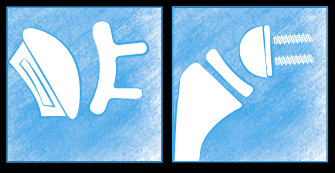
PARIS INTERNATIONAL SHOULDER COURSE 2019

February 14-16

Marriott Rive Gauche
PARIS, FRANCE

Shoulder Arthroplasty – Current Concepts



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Under the direction of
Ph. Valenti
M. Scheibel

PREFACE

CURRENTS CONCEPTS IN SHOULDER ARTHROPLASTY

2019

The Paris International Shoulder Course has become an inescapable event for anyone interested in Shoulder Replacement and is now the world's largest meeting on this subject. In absence but in particular in honor of our kind and charismatic friend « Philippe », we are welcoming you to the 4th edition, PISC 2019.

Our principal goal remains to offer to all levels - from junior trainees to experts in the field - a range of practical information with regard to new techniques and ideas. Particular importance should be given to younger shoulder surgeons, enabling them to increase their knowledge. The goal is to offer better treatment to our patients, and, with this in mind, we will propose a scientific program with up to date information concerning long-term results and latest innovations on shoulder prosthetic arthroplasties. This course belongs to you, and these 3 world-class scientific days will be of great benefit to everyone.

A large conference area will be set up for debates where experienced specialists will be able to share their knowledge and examples of difficult cases.

Importance should be given for technical innovations regarding the pre operative planning of shoulder arthroplasty. Live surgeries with various arthroplasties will be performed by the main experts of the world. And, of course, this event will be, once again, a great occasion to network with your colleagues from all over the world.

We look forward to welcoming you to Paris!

Philippe VALENTI, Markus SCHEIBEL
Chairmen PISC 2019

> THURSDAY FEBRUARY 14th, 2019

Complex shoulder fractures: Current strategies and controversies

How to Approach the Difficult Fracture?

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PART 1

Complex shoulder fractures: Current strategies and controversies

1/ PROXIMAL HUMERUS FRACTURE TREATMENT WHAT ARE THE CHALLENGES IN 2019?

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Proximal humerus fractures are very common.(1-4) Despite decades of research, controversy remains regarding the evaluation and management of these injuries. Recent publications have suggested that surgical treatment does not improve the outcome of nonoperative treatment.(5-7) However, a number of patients with proximal humerus fractures treated nonoperatively clearly do not do well, and in fact some patients do end up requiring surgery for the sequels of proximal humerus fractures.(8-13) As highlighted by Court-Brown et al in 2001(14), "proximal humeral fractures often occur in the fit elderly independent patient who is still a net contributor to society but who might well be converted to a degree of social dependency by the fracture." These facts highlight the challenges we continue to face in 2019: understanding the implications of fracture pattern and displacement remains a challenge, internal fixation with any method continues to have a high complication rate, and arthroplasty for complex fractures is difficult to perform and needs to be optimized.

UNDERSTANDING PROXIMAL HUMERUS FRACTURES

A major challenge in 2019 is that surgeons continue to have a hard time reaching agreement when classifying proximal humerus fractures or when recommending treatment. In the study by Petit et al, 8 surgeons at different levels of training were asked to review the imaging studies of 38 proximal humerus fractures and reported extremely low agreement when recommending treatment.(15) LaMartina et al recently reported that the outcome of surgery for proximal humerus fractures is worse when different surgeons are uncertain regarding treatment recommendations.(16)

The framework for classification proposed by Neer in 1970 continues to be widely used when evaluating proximal humerus fractures.(17) However, numerous studies have documented a relatively poor observer agreement (18-20), and alternative classification systems have not fared much better. (21, 22) This may be due in part to difficulties in reading proximal humerus fractures xrays and computed tomography (CT) scans.(23) But it is also due in part to the fact that the Neer classification and others mix fracture pattern and fracture displacement.(8) It is important to read carefully the words that Neer wrote in his review article in 2002(24): "Brown, the editor of the original article on the 4-segment classification, pointed out the importance of establishing displacement criteria. It was agreed, and the limits of 1.0 cm displacement or 45 degrees angulation were arbitrarily set. This is important for defining the minimal displacement (1-part), as well as the patterns of all displacements for decision making and for future outcome studies. However, it is not intended to dictate treatment. As displacement is a continuum, there will always be borderline lesions." So it turns out that displacement criteria were not generated through statistical analysis of data: they were arbitrarily set!

In an attempt to further understand the reasons for poor agreement when using Neer principles for classification and treatment recommendations, in 2005 we published a study that identified a number of issues, including difficulties with identification of fracture planes on plain xrays, different radiographic appearances with changes in position of the arm when xrays were taken, and others.(23) The findings of this study prompted a prospective study on 93 consecutive fractures treated nonoperatively and evaluated with radiographs of both shoulders and a CT scan of the fractured shoulder right after the fracture and at one year.(8) Through this study, we realized that there are very specific patterns of fracture, and that each pattern can present with various degrees of displacement. Both fracture pattern and fracture displacement correlated with clinical outcome. As a result of this study, we now try to first identify what fracture pattern we are dealing with, and then try to predict displacement. The development of this classification resulted from a collaborative research effort between Mayo Clinic and Fundacion Jimenez Diaz. These are the patterns contemplated in the Mayo/FJD classification (Figure 1):

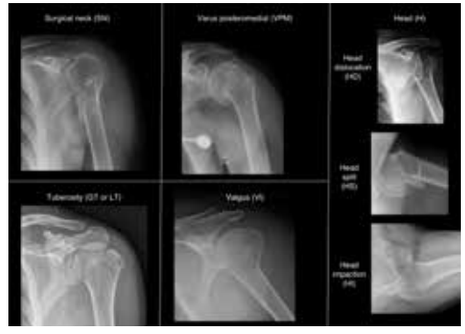


Figure 1
The Mayo/FJD classification of proximal humerus fractures

1. Surgical neck fractures (SN)

In these fractures, the plane that separates the diaphysis from the rest of the proximal humerus is at the level of the surgical neck (metaphyso-diaphyseal junction). In the majority of these fractures, the tuberosities are not fractured, although occasionally they can be fractured as well. The main potential adverse outcome with nonoperative treatment of these fractures is nonunion at the surgical neck, which is more likely to happen in the presence of substantial fracture displacement, fracture instability, or severely compromised healing potential (pathologic fractures, severe malnutrition, smoking).

2. Isolated tuberosity fractures (GT or LT)

These fractures are bony equivalents of a rotator cuff tear. The isolated fracture of the greater tuberosity can be the result of an avulsion in the setting of an anterior dislocation, or occur truly as an isolated injury. If it occurs in the setting of an anterior dislocation, residual displacement should be judged after reduction of the dislocation. Poor outcomes may occur secondary to impingement and weakness if the fracture heals with substantial displacement. The isolated fracture of the lesser tuberosity may occur as an avulsion of the subscapularis through bone, with or without an associated posterior dislocation. Displacement should be again measured after reduction of the posterior dislocation. The main potential adverse outcome with nonoperative treatment with these fractures is impingement of the tuberosities on the glenoid rim, or subacromial space. Sometimes, minimally displaced fractures of the tuberosities are difficult to visualize on radiographs, but can be identified on MRI.

3. Varus posteromedial impaction fractures (VPM)

VPM impaction fractures are very frequent. The plane separating the humeral head is located at the anatomic level and there is substantial comminution at the posteromedial neck-head junction. As a result, the humeral head articular cartilage faces posteriorly and inferiorly, and the shaft is in extension. The more comminution at the posteromedial level, the more unstable the fracture will be after surgical reduction. Treated nonoperatively, the amount of displacement correlates with outcome. (8) These fractures may have an associated fracture of the greater tuberosity, the lesser tuberosity, or both. The main potential adverse outcome with nonoperative treatment with these fractures is malunion resulting in decreased range of motion and loss of function.

4. Valgus impacted fractures (VI)

In these fractures, the plane separating the humeral head is located at the anatomic level as well, but the humeral head is displaced in valgus: comminution is on the lateral side, and the articular surface is oriented in excessive valgus. The majority of the times, the humeral head is facing superiorly or superolaterally, and the greater tuberosity is fractured and displaced medially and posteriorly. There can also be an associated fracture of the lesser tuberosity. Because of the valgus angulation, the tuberosity can be located above the articular surface, resulting in malunion and impingement. Depending on the severity of the disruption at the anatomic neck, the head might remain unstable and result in nonunion. Avascular necrosis is also seen more frequently in this fracture pattern compared to the varus posteromedial fracture pattern.

5. Fracture-dislocations, head splitting and head impaction fractures (DI, HS, HI)

In these fractures, the humeral head itself is either fractured or it is dislocated outside the confines of the glenohumeral joint capsule. The fracture may be divided in two or more separated segments (head splitting – HS), it may have a depression fracture anteriorly or posteriorly (head impaction – HI), it may be fully dislocated (HD), and there may be associated fracture planes separating the tuberosities and the shaft. The head features of these fractures trump other fracture categories.

Foruria et al. were able to correlate fracture pattern and fracture displacement with outcome when fractures are treated nonoperatively. (8) By doing so, it provides a frame of reference to determine whether surgery would translate into a functional improvement as compared with what would be expected to happen if a given fracture were to be treated nonoperatively.

INTERNAL FIXATION COMPLICATION RATES

Internal fixation in commonly performed for proximal humerus fractures that are substantially displaced but do not need to be salvaged with shoulder arthroplasty. Although multiple internal fixation modalities have been tried over time, plate fixation has become the most commonly used modality by many. When locking plate technology was first introduced for the surgical management of proximal humerus fractures, it was perceived that it would be the ultimate solution for these fractures.(25, 26) Unfortunately, the reported complication rates after internal fixation of proximal humerus fractures have continued to be unacceptably high.(27-29)

A number of potential pitfalls have been identified when plate fixation of proximal humerus fractures is attempted. These include poor initial reduction, failure to provide adequate inferomedial support in posteromedial fractures, failure to provide graft support for valgus impacted fractures, use of screws that are excessively long and penetrate the joint space, and failure to properly reduce or fix one or both tuberosities (Figure 2).

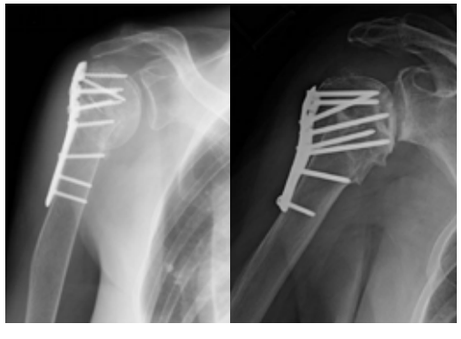


Figure 2
Failure of locking plate fixation for a proximal humerus fracture. A, Varus collapse secondary to poor reduction, secondary displacement, or both. B, Avascular necrosis

A number of strategies have been suggested to overcome these pitfalls. They include making sure that the reduction is adequate, using shorter screws without drilling into the head, use of screws directed to the calcar region, liberal use of bone graft, augmentation of screw thread purchase into the humeral head with bone cement, augmentation of the fixation using sutures through the rotator cuff and the plate. Some authors have reported improved outcomes using some of these techniques (30, 31). However, a relatively high rate of poor outcomes continues to be reported.

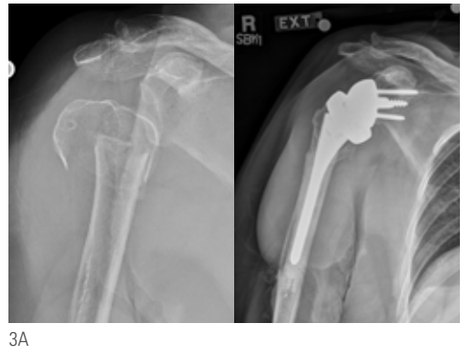
Barlow et al just reviewed the Mayo Clinic experience with plate fixation for proximal humerus fractures (unpublished data). Between 2005 and 2015, 173 consecutive proximal humerus fractures in patients over the age of 60 were treated \ with internal fixation using locking plating. Shoulders with less than 2 years of follow-up were excluded from the study unless they had undergone reoperation or radiographic failure. This left 131 shoulders available for final analysis (76% of eligible). The average age was 73 (60-95) years, and 84% were females. Fractures were classified according to Neer's criteria as 2-part fractures (61 – 47%), 3-part fractures (59 – 45%), and 4-part fractures (11 – 8%). Failure was defined as reoperation or radiographic evidence of secondary fracture displacement, intraarticular screw penetration, or loss of fixation. The average follow-up was 6.1 years. There was an overall failure rate of 34%. This correlated with fracture type, with a failure rate of 26% in 2-part fractures (16 failures), 39% in 3-parts (23 failures), and 45% in 4-parts (11 failures). Failure rate was also correlated with age, with 26% failure rate for patients in their 60s, 40% failure rate for patients in their 70s, and 48% failure rate for patients in their 80s. Zero of six patients in their 90s failed.

The main complications that led to failure were AVN with severe head collapse (screw penetration) in 23 patients (52% of failures), intraarticular screw penetration in 6 patients (14% of failures), hardware failure in 5 patients (11%), severe posttraumatic arthritis in 4 patients (9%), severe cuff failure in 3 patients (7%), nonunion in 2 patients (5%) and severe malunion in 1 patient (2%). When all surgical complications were included, there was an overall complication rate of 44%. The majority of complications that didn't lead to revision or failure were mild, asymptomatic AVN (6 cases), and mild, asymptomatic arthritis (3 cases). There was also one case of tuberosity escape, one asymptomatic loose screw, one case of frozen shoulder requiring injection, and 1 case of asymptomatic rotator cuff failure. Most patients with radiographic or clinical failure did not undergo reoperation. The overall reoperation rate was 11% (14 patients). This correlated with fracture type, with 7% of 2-part fractures (4 shoulders), 14% of 3-parts (8 shoulders), and 18% of 4-parts (2 shoulders) requiring reoperation.

Overall patient reported outcomes were satisfactory in patients without failure. VAS for pain averaged 0 at rest and 1 with activity. The average SANE score of this cohort was 92. At final follow up, for patients with failure (including those who had required revision operation), the VAS (rest) was 1, VAS (activity) was 2, and average SANE score was 77.
As such, it is clear that in 2019 we still need to improve our patient selection and surgical technique in order to provide better outcomes to our patients. That is part of the reason why intramedullary fixation is being revisited. (32) Until we improve substantially the outcome of internal fixation of proximal humerus fractures, it will not be possible to prove that surgery is better than nonoperative treatment, even though a number of patients do not do well with nonoperative treatment.

OPTIMIZING REVERSE FOR FRACTURE

For those substantially displaced fractures that cannot be reliably treated with open reduction and internal fixation, shoulder arthroplasty is oftentimes considered. Although hemiarthroplasty (humeral head replacement) with fixation of both tuberosities around the prosthesis used to be the procedure of choice, its outcome was unpredictable and oftentimes unsatisfactory.(33) In 2019, the majority of shoulder arthroplasties for fracture are performed with implantation of reverse components.(34)
Since reverse shoulder arthroplasty provides substantial improvements in pain and function in patients with massive irreparable cuff tears, initially surgeons felt that tuberosity healing was not very important when performing a reverse for fracture, and in some cases the tuberosities were resected at the time of arthroplasty.(35, 36) However, we now know that tuberosity healing in a satisfactory position correlates with a better outcome then reverse arthroplasty is performed for fracture, especially as it relates to the greater tuberosity.(37, 38) (Figure 3).



3A

3B

3C

3D

Figure 3
Reverse for fracture. A. Preoperative radiograph. B, Radiograph at two years shows adequate tuberosity healing. C, Elevation, D, External rotation. E, Internal rotation

The problem is that reverse for fracture with tuberosity reconstruction is a demanding procedure. Not only the surgeon must be familiar with the overall nuances of reverse shoulder arthroplasty, but also understand how to implant the humeral component in the correct height and version, and how to properly position and fix the tuberosities. This is especially problematic for general orthopedic surgeons or even trauma surgeons not completely familiar with reverse shoulder arthroplasty.

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2/ A NEW TREATMENT ALGORITHM FOR PROXIMAL HUMERAL FRACTURES

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We developed a new evidence-based treatment algorithm for proximal humerus fractures (PHF). Main input parameters used for decision making are patient's demands, bone quality and fracture type. The aim of this study was to assess its feasibility and clinical outcome. We analyzed the outcome of 192 patients (58 male, 134 female, mean age of 66 years) treated for isolated PHF between 2014 and 2015 in our institution. We treated 160 (83%) according to the algorithm, of those 132 patients, 36 with ORIF, 4 hemiarthroplasties (HA) and 20 with reverse total shoulder prosthesis (RTSA). The mean EQ-5D before trauma and 1 year after treatment were practically equal 0.88 versus 0.9 points. At 1 year follow-up, the mean relative Constant score was 95% and mean SSV 84%. Unplanned surgery was needed in 3 conservatively treated patients, 16 times after an ORIF and twice after HA. In conclusion, the algorithm proved to be a helpful tool, leading to good clinical results after 1 year and good quality of life with the best results in the conservative treatment arm and after RTSA. In future, the rate of unplanned surgery after ORIF should be reduced.

INTRODUCTION

Randomized controlled trials about operative treatment modalities for PHF about have not shown a significant functional benefit of surgical over conservative treatment.[13,14,26,27,34,37] Although providing evidence, those studies result in fragmented knowledge for particular fracture types and particular treatment options. In our opinion , treatment strategy should integrate also patient specific factors, such as individual patients' demands and bone quality.[5,21,23,25,43] Therefore, we developed a new evidence based algorithm for PHF.[39,40]

THE ALGORITHM

One part of the algorithm considers young and active patients usually up to the age of 65 years (Fig 1). In these patients the aim is to achieve maximal shoulder function, according to the current literature. [2,3,10,11,15,16,18,22,32,33,35,39]
The other part of the algorithm considers elderly patients, older than 65 years (Fig 2).[39] In a first step, their activity level and general health status are assessed. If patients come from a nursing home, they are treated conservatively, the aim being pain relief [13,14,26,27,34] (Fig 2). If patients are still active and independent before the fracture, the goal is to achieve maximal shoulder function. The treatment of these elderly patients is adapted according to their local bone

Figure 1
Algorithm for proximal humeral fractures (Part I)

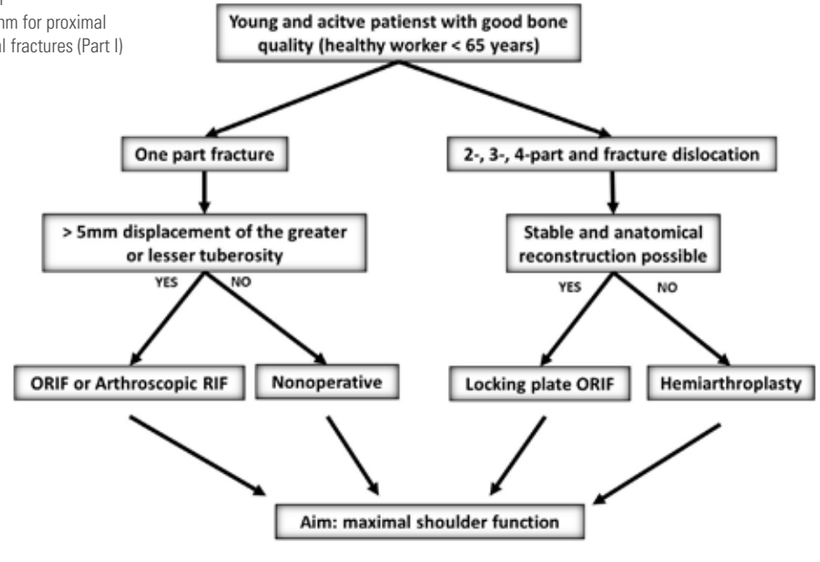
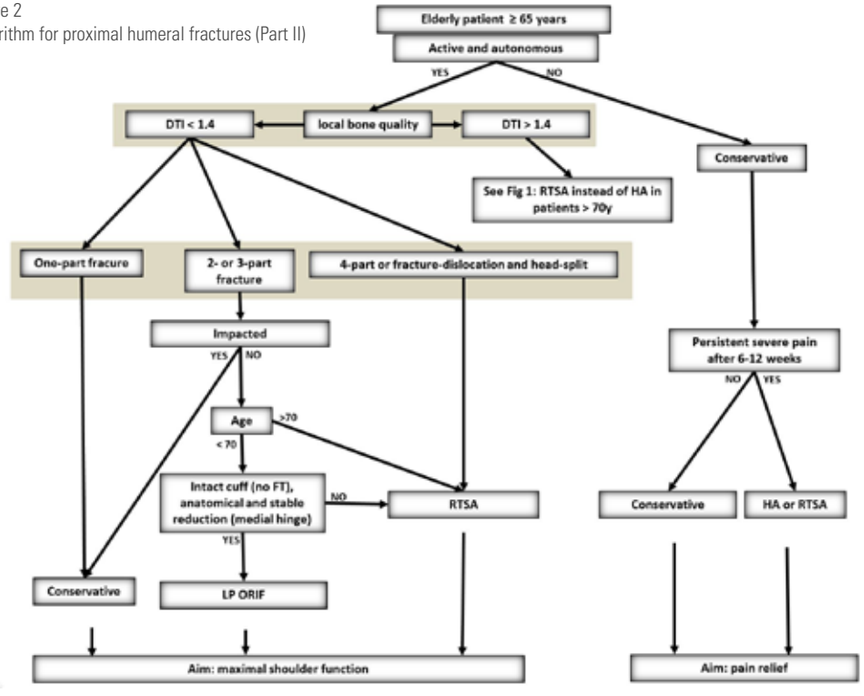


Figure 2
Algorithm for proximal humeral fractures (Part II)



quality (biological age), as this is known to influence the outcome of ORIF substantially.[5,21,23,41,43] Patients with good bone quality are treated like young and active patients (Fig 1), the only difference being that RTSA is used for patients > 70 years instead of hemiarthroplasty (HA).[4,9,12,38,46] For patients with poor bone quality, treatment depend on the fracture configuration according to the best available evidence (Fig 2).[6-8,17,19,22,28,39]

ALGORITHM PERFORMANCE STUDY

We included patients treated for isolated PHF between January 2014 and December 2015. At initial presentation, the patients' quality of life before the trauma was assessed using the EQ-5D[26-28] and their level of independence estimated. Local bone quality DTI! and the fracture type according to Neer were assessed on AP and lateral radiographs. At follow-up consultations after 3 and 12 months a trained study-physiotherapist examined all patients clinically including EQ-5D, Constant scores (CS) and subject shoulder values (SSV). Radiographic examination included AP views in internal and neutral rotation as well as axial and lateral views. Any complications or unplanned surgery were noted in the protocol.

A total of 192 patients could be included into this study, 58 male (mean age 58.4, range 18 to 90 years) and 134 female (mean age 69.1, range 19 to 97 years). The fracture classification was based on conventional radiographs with additional CT required in 84 patients (44%). There were 85 (44%) 1-part, 75 (39%) 2-part, 15 (8%) 3-part and 17 (9%) 4-part fractures. The mean DTI was 1.53 (range 1.22 to 2.1) in the male and 1.45 (range 1.11 to 2.35) in the female population. In total, 132 patients were treated conservatively, 36 with ORIF and 24 with primary prosthesis (4 HA, 20 RTSA). Of all patients included, 160 (83%) were treated according to, and 32 (17%) not according to the algorithm.

Of the 192 patients included, a total of 174 (91%) patients were available for outcome analysis. Their mean quality of life (EQ-5D) before the fracture was 0.88 (range 0.2 to 1) and 1 year after treatment it was 0.9 (range 0.1 to 1) (p=0.9). The mean absolute and relative CS at final follow-up were 72.5 points (range 21 to 98 points) and 95% (range 32.8 to 138.4%) respectively. The mean SSV at final follow-up was 84.4% (range 35 to 100%).

Patients treated conservatively according to the algorithm had significantly better functional outcomes than those treated conservatively but not following the algorithm. Patients treated with RTSA although this was not according to the algorithm, showed a tendency towards better pre-injury EQ-5D and better final functional outcomes. Three patients needed unplanned surgery after conservative treatment due to painful secondary displacement. The revision rate after ORIF was the highest (n=16). Plate removal was needed in 8 cases, additional arthroscopic arthrolysis due to stiffness in another 3 patients. Early loss of reduction (n=3), avascular necrosis (AVN, n=1) and secondary cut out (n=1) were further reason for revisions. Two patients with primary HA and none of the patients with RTSA needed revision during the study observation period. There was no significant difference in the rate of unplanned surgery between patients treated according to the algorithm and those who were not.

DISCUSSION

To the best of our knowledge this is the first algorithm performance study for proximal humerus fractures. The adherence to the algorithm was high (83%), which proves the feasibility of using it in daily clinical practice in a level 1 trauma center. The overall clinical results and quality of life after 1 year were found to be very satisfying in all treatment groups apart from patients treated with hemiarthroplasty.

Patients treated according to the algorithm regularly reached the quality of life (EQ-5D) they had before the fracture. Our mean pre-injury EQ-5D values are comparable to the studies of Olerud et al.[26] However, with the randomization of their patients to either conservative or operative treatment, they were unable to attain these results again after 1 and 2 years. Also their 1-year functional outcome (absolute CS) was mainly lower compared to our results. In our opinion, this shows the downside of randomization of patients to either conservative or one operative treatment and the need for more distinct stratification. In our collective, apart from patients treated with HA, the overall functional outcome after 1 year was successful, especially if algorithm was followed correctly.

Conservative Treatment

Conservative treatment of 1-part fractures worked very well for young and elderly patients. Clinical results were excellent after 1 year and unplanned surgery due to secondary displacement was rarely needed. This is in accordance with earlier studies.[22,24] Also, conservative treatment of varus or valgus impacted 2-part fractures in elderly patients with low bone quality was successful. We found mainly good clinical results in these patients, which is in accordance to the studies of Court-Brown et al.[7,8] We chose conservative treatment, regardless of the fracture type (apart from fracture dislocations), for dependent low-demand patients who live in nursing homes. None of them needed unplanned surgery for pain relief. Conservative treatment needs to be specifically indicated in order to achieve consistently good clinical results.

Open reduction and internal fixation

In our algorithm, ORIF was mainly indicated for young and active patients or elderly patients with high demands and good bone quality.[21,23,43] In active patients with low bone quality, the indication for ORIF was restricted to certain fracture types that are specifically amenable to ORIF (two-part or valgus impacted fractures).[19,28] Due to our consistent selection of patients for ORIF, we achieved very satisfying clinical results after 1 year, especially if the treatment was according to the algorithm. Compared to other studies we had fewer severe complications like AVN or head screw cut outs,[42,44] which may be the result of our very specific patient selection. However, the rate of unplanned surgery was higher compared to other studies[30,31,44,45] with a high rate of implant removal in our collective. This may partially be explained by the more prominent implant we used compared to most other studies.[31,42,45] A further explanation for the higher revision rate might be that several surgeons with different levels of experience in shoulder surgery performed ORIF. As a direct consequence of this relatively high revision rate, we changed the implant to a less prominent one.

Hemiarthroplasty

HA was only good for pain relief and led to limited function in our patients, which reflects the findings of a recent study with the same implant.[47]

Reverse total shoulder arthroplasty

RTSA is becoming the mainstay of treatment for displaced proximal humerus fractures in the elderly[17,20,38] with clearly better results than hemiarthroplasty.[12,38,46] Our patients also had very satisfying functional outcomes after 1 year without requiring revision surgery. Although the age limit was set at 70 years, we found that most of the patients between 65 and 70, previously considered for HA, were instead treated with RTSA. These patients had a better pre-injury quality of life and tended to have better functional outcomes after one year. Apparently, these patients were very active and the surgeons wanted to offer them the best possible solution, which was RSTA rather than HA. The age cut off for RTSA is still under debate with the increasing tendency to lower it as long term RTSA data (not for treating fractures) are promising[2] and the results after HA consistently unpredictable.[47]

FUTURE DEVELOPMENTS OF THE ALGORITHM

Firstly, to lower the implant removal rate, we will change to a low profile locking plate. Secondly, because RTSA was preferred to HA in patients > 65 and < 70 years, and we experienced very limited outcomes after HA, the age limit for RTSA will be reduced to ≥ 65 years.

CONCLUSIONS

The algorithm proved to be a helpful tool, leading to good clinical results after 1 year and good quality of life. In future, the rate of unplanned surgery after ORIF should be reduced.

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3/ CHALLENGES OF PROXIMAL HUMERAL FRACTURE DISLOCATIONS

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INTRODUCTION

The incidence of glenohumeral dislocations in the United States is 24 per 100,000 person-years, with half of those occurring in patients under the age of thirty[63]. Historically, fractures of the shoulder girdle were reported in roughly a quarter of dislocations, however this number most likely underestimated the true incidence prior to the advent of advanced imaging techniques[49]. Although glenohumeral dislocations can occur at any age, injury patterns vary significantly. While the characteristic injury in a young patient involves a labral tear, with or without a concomitant fracture of the glenoid rim, older patients more often present with rotator cuff tears or fractures of the proximal humerus. Fracture dislocations pose a challenging spectrum of pathology to the treating surgeon and require a keen understanding of osseous and soft tissue anatomy about the shoulder. Management is guided by the presence of persistent dislocation or subluxation of the humeral articular surface relative to the glenoid face (glenohumeral instability) and proximal humeral fracture fragment morphology, based on the severity of the deformity, angulation, comminution and potential for symptomatic sequelae, such as persistent instability, osteonecrosis, fracture malunion, nonunion and posttraumatic arthritis and stiffness.

INITIAL EVALUATION

Initial evaluation of patients with shoulder fracture dislocations must include a thorough neurovascular exam as dislocation of the humeral head can produce traction injuries of the brachial plexus and axillary artery. The most common brachial plexus injury seen in these cases is often a mixed plexus injury, typically involving the axillary nerve, followed by radial, musculocutaneous, and ulnar nerves. It is important to distinguish between deltoid atony, which may present as pseudosubluxation of the humeral head, and a true axillary nerve palsy. Inferior humeral head subluxation (pseudosubluxation) is commonly observed after proximal humerus fractures and typically resolves with time and restoration of deltoid tone. The cause of this is not well understood. In pseudosubluxation, the humeral head will "sag" inferiorly on radiographs, but deltoid motor function will be intact with volitional effort. Conversely, axillary nerve injury will result in diminished deltoid contraction and paresthesias over the lateral deltoid. EMG studies have reported rates of nerve dysfunction in up to 45% of patients after proximal humerus fractures and dislocations[12]. Patients over the age of 60 are at greater risk of sustaining nerve injuries and are also more likely to present with injury to more than one nerve, an otherwise uncommon sequelae[47]. This is thought to be the result of less robust connective tissue layers surrounding the nerves. While most patients recover complete function of the nerve within a matter of months, there is some evidence to suggest that long term functional outcomes may still be affected[62]. Assessment requires evaluation of both motor and sensory components of the entire brachial plexus.

Older patients are also at increased risk of vascular injury in the setting of shoulder fracture dislocations. Age related atherosclerotic changes decrease the elasticity of the axillary artery making it more prone to injury. In uncomplicated shoulder dislocations the rate of vascular injury is roughly 1% and the incidence is substantially higher when a fracture is present[58]. An abnormal vascular exam warrants CT angiography to look for an arterial injury, however even when a vascular injury is present the physical exam may be normal due to considerable collateral circulation about the shoulder. Angiography should also be considered in chronic dislocations in order to localize the artery prior to surgery as it may become adherent to the proximal humerus. Over half of patients with arterial injuries will have associated brachial plexus injuries.

Initial radiographic assessment of proximal humerus fracture dislocations includes a shoulder series complete with orthogonal views. X-rays may underestimate the degree of greater tuberosity displacement, particularly in the posterior direction. By measuring displacement of the greater tuberosity in multiple x-ray views both accuracy and reliability are improved[42]. In contrast, the location of the lesser tuberosity makes accurate assessment of fracture extent, comminution and displacement difficult with plain x-rays and a CT scan is the imaging modality of choice. Additionally, plain radiographs may poorly demonstrate glenoid injuries and therefore it is recommended that in fracture dislocations a CT scan be obtained. In addition to demonstrating all fracture fragments (such as lesser tuberosity fractures, head splitting fractures, glenoid fractures, etc.) the CT scan is also helpful to assess the quality of the rotator cuff musculature, as fatty infiltration, described by Goutallier et al., may indicate the presence of chronic rotator cuff tears or deficiency, and may impact treatment choice[20].

PATHOANATOMY

The most widely used classification system for proximal humerus fractures was first outlined by Neer in 1970. Based on Codman's originally described physeal lines, 4 parts were defined; namely the articular segment, the greater and lesser tuberosities, and the humeral shaft. While Neer's classification identifies the subgroup of fracture dislocations amongst proximal humeral fractures, it does not help describe injuries to the glenoid. Newer classification systems have been proposed, however the Neer system remains the primary language through which these injuries are discussed and an understanding of the deforming forces is critical for both operative and nonoperative management.

Knowledge of the vascular anatomy is also essential in managing shoulder fracture dislocations. Historically, the anterior humeral circumflex artery was believed to the supply the majority of the blood flow to the humeral head[18]. The high frequency with which this artery is disrupted in proximal humerus fractures along with the relative infrequency of humeral head osteonecrosis, led Hettrich et al. to posit that the posterior humeral circumflex supplied more of the humeral head than was previously believed[23]. They confirmed this hypothesis in a cadaveric study demonstrating that the posterior humeral circumflex artery supplies 64% of the blood flow to the humeral head. Great care should be taken intra-operatively to preserve soft tissue attachments, in particular the posteromedial capsule, and avoid further disruption of the blood supply.

MANAGEMENT

Management of proximal humeral fracture dislocations depends on the injury pattern as well as patient demographics and functional goals. While closed reduction of the glenohumeral joint often improves the alignment of isolated tuberosity fragments following tuberosity fracture dislocation patters, it is not likely to be as successful and may cause further disruption of the fracture fragments in more complex three and four-part fracture dislocations.

Surgical treatment is aimed at restoration of anatomy in fracture patterns amenable to fixation, with attention centered on concentric joint reduction, repair of larger displaced glenoid fractures and restoration of proximal humeral anatomy, especially displaced tuberosities. While percutaneous pinning has been advocated for select displaced proximal humerus fractures, more severe injury patterns, especially[3,4]-part proximal humerus fractures or those with displaced glenoid fractures, locked proximal humeral plating is often the preferred fixation choice, although many of these patters may also be managed with arthroplasty. Classically, hemiarthroplasty was used for complex fractures and fracture dislocations of the shoulder due in part to concerns over the risks of nonunion, hardware failure and osteonecrosis. However, concerns over recurrent instability and, more commonly, tuberosity malunion or nonunion has led most surgeons to advocate the use of reverse shoulder replacement in management of these more severe injuries not amenable to fixation.

GREATER TUBEROSITY FRACTURES

Initial closed reduction of the glenohumeral joint will frequently result in indirect reduction of isolated greater tuberosity fractures. Conservative management is reasonable in cases with minimal displacement and recurrent instability is uncommon once the tuberosity fracture heals[38]. Five millimeters of displacement of the greater tuberosity is generally accepted as an indication for operative management. However, it has been suggested that displacement of as little a 3mm may impair outcomes in high demand patients engaging in overhead activities[41, 43]. Superior and posterior displacement of the greater tuberosity fragment results in impingement and has also been shown to increase the force required for the deltoid to elevate the arm[8]. Even in cases where initial displacement after closed reduction has been deemed to be acceptable, subsequent fragment migration is often seen. The risk of delayed displacement is highest among younger patients and in the setting of a dislocation[21]. Therefore close radiographic monitoring is necessary when conservative management is chosen.

Operative management may performed through a superior or deltopectoral approach and arthroscopic treatment has also been described. Greater tuberosity fragments are frequently comminuted with only a thin shell of bone. This makes isolated screw fixation unreliable in many cases, and incorporation of the rotator cuff into the repair using heavy non-absorbable sutures is often indicated. Care must be taken to avoid over-reduction of the fragment.

LESSER TUBEROSITY FRACTURES

Lesser tuberosity fractures are an uncommon injury and are particularly rare in isolation. Osseous avulsion of

the subscapularis has been described in adolescents, however in adults lesser tuberosity fractures are often associated with posterior glenohumeral dislocations. In comparison to other types of proximal humeral fracture dislocations, these injuries comprise a younger patient demographic and are usually the result of a higher energy mechanism of injury.

Similar to greater tuberosity fracture dislocations, the lesser tuberosity fragment tends to reduce to a degree with reduction of the glenohumeral joint. While non-displaced fractures may be treated non-operatively, they are uncommon. A number of injury characteristics make acute open reduction and internal fixation the preferred treatment for a majority of lesser tuberosity fractures. In many cases the fragment includes a portion of the articular surface, which necessitates congruent reduction under direct visualization. Additionally, involvement of the bicipital groove can result in subluxation of the biceps tendon into the fracture site, blocking reduction of the tuberosity48. There are currently no guidelines as to the amount of displacement that can be tolerated. The fragment may continue to displace over time due to the deforming force of the subscapularis and results of fixation in chronic injuries are less predictable.

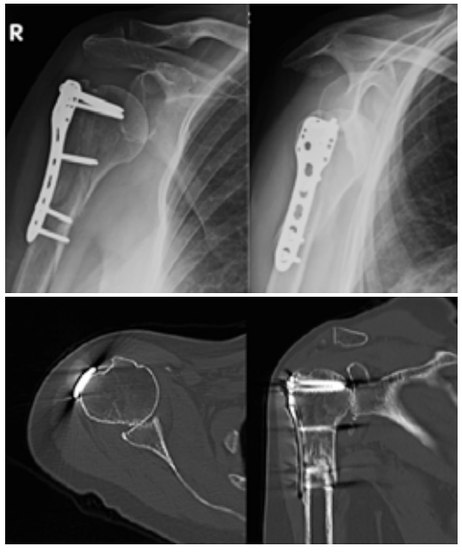
Lesser tuberosity fractures may be fixed with heavy non-absorbable transosseous sutures or with screws for larger fragments. When undertaking screw fixation it is important to direct the screws towards the posteroinferior aspect the greater tuberosity to avoid glenohumeral joint penetration. There are few outcome studies pertaining to these injuries. However, based on the available literature, post-operative fracture displacement and recurrent instability have not been reported[30, 48].

OSTEOSYNTHESIS WITH PLATE FIXATION

Early outcome studies examining osteosynthesis for complex proximal humerus fractures yielded discouraging results with unacceptably high rates of malunion, nonunion, and osteonecrosis[35, 50, 64]. Results have improved with the relatively recent introduction of locking plates. These plates preserve periosteal blood supply and decrease the rate of varus collapse and screw penetration which plagued early fixation attempts. They also allow for calcar screw placement along the inferior humeral neck, further reducing the incidence of failure. Many plates include suture holes along the periphery. Heavy non-absorbable sutures can then be used to augment fixation of the cuff and tuberosities, as these fragments are often comminuted.

More recent comparisons of locked plate fixation versus hemiarthroplasty for three- and four-part fractures have demonstrated better outcomes with osteosynthesis with respect to complication rates and functional outcomes[55]. Although significant improvements have been made in proximal humeral fracture fixation, screw penetration and varus collapse continue to be among the most frequent complications encountered after this procedure. Egol et al. reported screw penetration in 16% of patients at short term follow up[14]. Because of the increased risk of screw penetration, initial varus malalignment more than 20 degrees is considered by some to be a relative indication for arthroplasty over internal fixation, particularly in older patients[56].

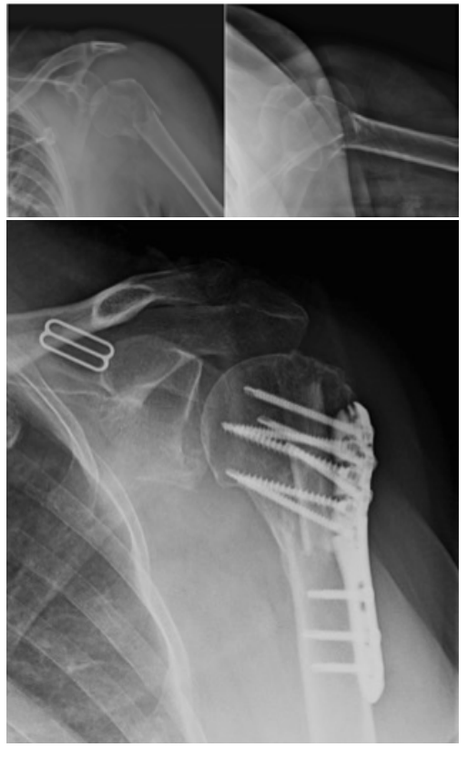
Recurrent instability following internal fixation is rare in this patient population, therefore soft tissue injuries involving the capsule and anteroinferior labrum are typically not addressed. Repairing these structures may result in increased stiffness in these patients who are already prone to develop stiffness post-operatively[57]. On the other hand, concomitant glenoid fractures should be addressed at the time of surgery. Though little is known about the incidence of glenoid fractures in proximal humerus fracture dislocations, glenoid involvement should not be overlooked as it may compromise subsequent joint congruity and stability (Figures 1 and 2).



Figures 1 & 2
63 year old female who sustained a proximal humeral fracture dislocation and underwent operative fixation at an outside institution. Patient presented with pain and loss of function and radiographs demonstrated varus malunion and failure to treat associated glenoid rim fracture, resulting in malunion and post-traumatic instability and ultimately arthritis.

ENDOSTEAL STRUT AUGMENTATION

Proximal humerus fractures are the third most common fracture in the geriatric population, following hip and distal radius fractures. As the geriatric population grows, the incidence of these fractures is expected to increase. Epidemiologic studies have also demonstrated an increase in age-specific incidence, with one Finnish study predicting that the overall incidence of proximal humerus fractures will triple over a thirty year period[40]. A number of studies have shown equivalent functional outcomes in elderly patients treated with locking plate osteosynthesis for three and four-part fractures when compared with younger patients[27, 54]. However, concern remains regarding high rates of screw penetration in elderly patients with osteoporotic bone[14, 34, 39]. In an effort to improve fracture fixation in the geriatric population, endosteal strut allograft augmentation was introduced (Figures 3 and 4).

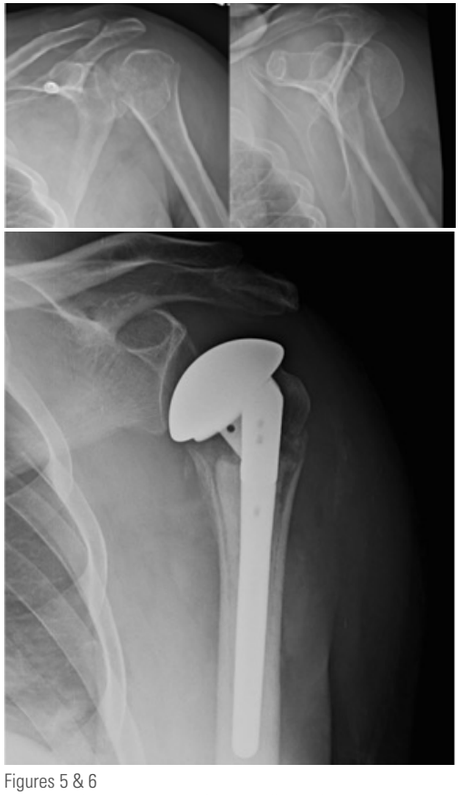


Figures 3 & 4
Conversely, this is a 62 year old woman with a similar injury pattern who sustained a 3 part fracture dislocation, with an anterior inferior rim fracture. Anatomic reduction and fixation of the proximal humerus was achieved with locked plating, supported by an intramedullary fibular allograft strut to aid in maintenance of humeral head height, along with glenoid rim repair utilizing a subscapularis upper third takedown and anchor repair.

Promising results with regards to load to failure and construct stiffness have been seen in biomechanical investigations of cadaveric models with medial comminution treated with intramedullary fibular strut grafts and locked plate fixation[2, 9]. Clinical outcomes have been shown to be equivalent to non-geriatric patients with this technique[24].

HEMIARTHROPLASTY

In 1970, along with his classification system, Neer reported results of operative treatment for three- and four-part fractures as well as fracture dislocations. For these complex injuries he reported 90% excellent and satisfactory results with hemiarthroplasty and concluded that this was the optimal treatment method[35]. However, subsequent studies have demonstrated less favorable results with unpredictable outcomes[4,19, 27]. A technically challenging procedure, hemiarthroplasty in the fracture setting relies on anatomic reduction, secure fixation, and ultimate healing of the tuberosities in order to obtain acceptable functional outcomes (Figures 5 and 6).



Figures 5 & 6
64 y/o male s/p posterior fracture dislocation treated by hemiarthroplasty and anatomic tuberosity repair.

Establishing appropriate soft tissue tensioning is critical to restore function of the rotator cuff while avoiding fixation failure from over-tensioning. The lateral fin of the implant should be placed thirty degrees posterior to the bicipital groove to avoid excessive retroversion and subsequent over-tensioning of the posterosuperior cuff[28]. The anatomic head height must also be recreated relative to the tuberosities (6-8mm) and upper edge of the pectoralis major insertion (5.6cm)[60].

Even in expert hands, rates of initial malreduction of the greater tuberosity as high as 25% have been reported with an additional 23% of cases displacing post-operatively[4]. In this study, average forward flexion was only 101° and external rotation was 18°. Tuberosity nonunion and resorption are also common and tend to increase with age. In spite of these shortcomings, hemiarthroplasty still has a role in the management of proximal humeral fracture dislocations (Figure 7).

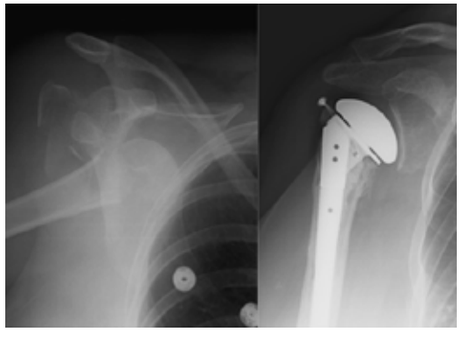
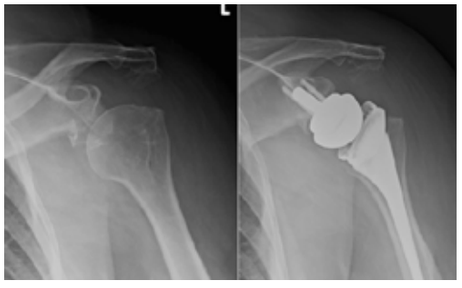


Figure 7
Fifty-eight year old woman treated with a hemiarthroplasty for a four-part fracture dislocation.

It is primarily indicated in younger patients with unreconstructable fractures, including head split patterns, those where the humeral head is devoid of soft tissue attachments, and cases where osteoporotic bone or other patient factors make osteosynthesis a less favorable option.

REVERSE SHOULDER REPLACEMENT

Since the introduction of the reverse shoulder arthroplasty (RSA), indications for this procedure have expanded dramatically. A growing indication is in the setting of complex three- and four-part proximal humerus fractures and fracture dislocations in the elderly population (Figure 8).



Figures 8
Sixty-two year old very obese the woman with a large anterior glenoid fracture following a shoulder dislocation. The glenoid rim injury was too comminuted for operative repair and therefore the patient was treated with a reverse shoulder arthroplasty and glenoid reconstruction with autograft utilizing the humeral head, incorporated in the baseplate fixation within the patients native glenoid.

The current literature supports reverse shoulder arthroplasty over hemiarthroplasty in geriatric patients. When compared with hemiarthroplasty for patients over the age of 65, RSA has been shown to more reliably improve function although higher complication rates are still reported[11, 16]. While outcomes are better with RSA when the tuberosities heal, good outcomes can be achieved even when the tuberosities do not heal[37, 51]. This is not the case for hemiarthroplasty in which post-operative function is dependent on healing.

Direct comparison of primary reverse shoulder arthroplasty to locking plate fixation for complex proximal humerus fractures is lacking. However, RSA has been used successfully in the revision setting for patients who previously underwent locking plate fixation. Patients who undergo secondary RSA experience significant improvements in pain and function, but higher complication rates when compared to primary RSA[52, 53].

Anatomic reduction and healing of the greater tuberosity, while not critical to the success of the procedure, has been shown to improve external rotation[15]. Over-reduction, particularly of the greater tuberosity to the implant, is often seen as this fragment is typically a thin wafer of bone. Morcellized bone taken from the excised humeral head may be used to offset the greater tuberosity from the implant in these cases. Fixation of the tuberosities first with horizontal sutures followed by vertical sutures helps in maintaining secure reduction while avoiding over-reduction. The addition of a medial cerclage further improves the stability of the repair. Fixation of the lesser tuberosity, thereby restoring the subscapularis, is thought to be less critical. Conflicting evidence exists as to whether repair of the subscapularis provides meaningful improvement in implant stability[10, 13]. Our preference is to routinely fix the lesser tuberosity, particularly in cases presenting with a dislocation.

SEQUELAE

Long-term sequelae of proximal humerus fractures and fracture dislocations can be difficult to treat, with historically unpredictable functional outcomes and high rates of post-operative complications. Boileau et al. proposed a classification system for fracture sequelae in an effort to guide treatment of a relatively heterogeneous group of patients[5]. In their classification system, intra-capsular sequelae, namely humeral head collapse or necrosis (type 1) and locked dislocations or fracture dislocations (type 2), are distinguished from extra-capsular sequelae, namely surgical neck nonunion (type 3) and tuberosity malunion (type 4). They propose that intra-capsular sequelae typically do not require an osteotomy of the greater tuberosity, while extra-capsular sequelae often do, a distinction that greatly impacts surgical treatment options. The most favorable outcomes following secondary procedures have historically been seen with post-traumatic arthritis, followed by osteonecrosis, and nonunion with the worst results seen in cases of malunion[31].

OSTEONECROSIS AND HUMERAL HEAD COLLAPSE

Rates of osteonecrosis of the humeral head following proximal humerus fractures increase with increasing disruption of the soft tissue attachments. For example, rates of AVN have been shown to be at least two to three times as high in four-part fractures compared to three-part fractures. Interestingly, humeral head necrosis in setting of chronic posterior fracture dislocations involving the lesser tuberosity has been reported at a rate of 22%[30]. Hertel et al. assessed humeral head perfusion intra-operatively and found that several injury features were associated with ischemia; namely anatomic neck fractures, medial hinge disruption, and shorter medial calcar extension[22]. The importance of the posteromedial capsule in maintaining vascularity to the humeral head has further been born out in that valgus impacted four-part fractures have significantly lower rates of osteonecrosis than those in which the medial hinge is disrupted[26]. Dislocation of the humeral head has not been found to predict humeral head necrosis independent of these factors[61]. Additionally, intra-operative ischemia has not been shown to be predictive of later necrosis[3]. This suggests that anatomic reduction and stabilization may allow for reperfusion of the humeral head.

While the risk of osteonecrosis has been well described, it remains difficult to predict and its role in decision making at the time of the primary surgery is not clear cut. The clinical impact of humeral head osteonecrosis is often inconsistent, with outcomes affected by the proportion of the humeral head involved as well as the presence of a malunion. Clinical results for patients who developed osteonecrosis in the absence of a malunion following plate osteosynthesis have been shown to be equivalent to the results of hemiarthroplasty[17]. For this reason, every effort should be made to maintain and fix the humeral head in young patients in particular.

Secondary treatment in patients who develop symptomatic collapse is typically with prosthetic replacement using either a hemiarthroplasty or anatomic total shoulder replacement. Pre-operative MRI is valuable in these cases in order to determine the extent of the necrosis as well as the integrity of the rotator cuff. Significant improvements with respect to range of motion and function can be achieved with unconstrained prosthetic replacement for humeral head necrosis provided in the absence of cuff disruption or greater tuberosity malunion[33, 58].

MALUNION AND NONUNION

Unlike osteonecrosis, extra-capsular sequelae have been shown to have unpredictable results when treated with unconstrained arthroplasty[1]. Prior to the introduction of newer implant designs, malunions of proximal humerus fractures were managed with a hemiarthroplasty or anatomic shoulder replacement with a standard stem length. Due to the position of the humeral head relative to the shaft, this procedure generally requires an osteotomy of the greater tuberosity in order to align the full length of the stem with the shaft, with resulting high complication rates and poor outcomes[6, 7]. The introduction of short stemmed and stemless prostheses may obviate the need for a greater tuberosity osteotomy, although outcome studies are lacking. Reverse shoulder arthroplasty has recently been shown to produce reasonably good outcomes for both malunion and nonunion in elderly patients, as well as those with intracapsular sequelae and cuff deficiency[44, 45, 46]. However, in spite of these relatively promising results for a difficult problem, outcomes appear to be worse than those reported in the literature for primary reverse in the fracture setting with high complication rates. Young patients present a more difficult population to treat due to concerns regarding longevity and complications associated with prosthetic replacement. In young patients where the primary complaint is impingement without significant arthrosis, weakness, or stiffness, an arthroscopic tuberoplasty with or without retensioning of the cuff may be beneficial[29]. Alternatively a number of osteotomy techniques have been described including laterally based closing wedge and greater tuberosity advancement osteotomies[32, 36]. As the indications for these procedures are limited, only small series exist in the literature.

CONCLUSION

Proximal humeral fracture dislocations are a complex category of injuries with a myriad of treatment options depending on fracture morphology, patient demographics and functional goals. While management of isolated tuberosity fractures depends on residual displacement following closed reduction, the vast majority of complex three- and four-part fracture dislocations require operative management. In young patients every effort should be made to retain the humeral head with internal fixation, reserving prosthetic replacement for older patients. Improvements have been made in the management of fracture sequelae including osteonecrosis, nonunion and malunion although treatment remains challenging with high complication rates.

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4/ WHAT YOU NEED TO KNOW ABOUT HEAD-SPLIT FRACTURES

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INTRODUCTION

Proximal humerus fractures account for approximately 6% of all fractures [1]. Several different types of proximal humerus fracture patterns with different treatment options exist. A particular fracture pattern is the so-called head-split fracture, which is rarely encountered but represents a serious treatment challenge due to involvement and sometimes comminution of the articular surface [24]. The term head-split is often associated with consecutive avascular necrosis (AVN), even though this condition can only be considered a poor to moderate predictor of humeral head ischemia [11]. In general, there is a lack of clear definition and classification for head-split fractures in the current literature which makes the already scarse number of outcome reports even more difficult to interpret.
The goal of this article is to provide a review of the available knowledge regarding pathomorphology, diagnosis and treatment of head-split fractures.

EPIDEMIOLOGY AND MECHANISM OF INJURY

Patients presenting with head-split fractures generally can be divided into two groups. One group includes younger and predominantly male patients involved in high-energy trauma (i.e. bicycle-, motor -, car accident, epileptic seizure) with typically good bone quality and good potential for revascularization [4,7]. The other group includes elderly mainly female patients involved in low-energy trauma (i.e. simple fall) and typically poor bone quality and limited regenerative potential [9].

PATHOMORPHOLOGY AND CLASSIFICATION

Head-split fractures occur when the articular surface area of the humeral head cleaves into two or more parts as it impacts against the narrow „anvil" of the glenoid [25] Generally, a consensus on the definition of head-split fractures does not exist and the inter-observer agreement in the diagnosis of a head-split fracture is poor even in the presence of a CT scan with 3D reconstruction [24]. Some authors suggest that a head-split fracture is present if at least 20% of the articular surface are involved [28]. However, area estimations of the humeral articular surface are unreliable and accurate measurement is difficult with conventional software [17].
There are a vast number of different classifications for proximal humerus fractures. The most frequently used is the Neer classification published in 1970 [21]. Neer classified head-split fractures along with 'impression' fractures in the group of 'articular surface defects' as quote: "special fracture-dislocations, because parts of the articular surface are displaced outside of the joint" [21].
The AO classification describes head-split fracture as 11C2-3 which includes a "transcephalic fracture line" [19]. "This (line) runs obliquely, somewhat parasagittal. A significant portion of the head remains attached to the greater tuberosity" [13].
Hertel et al. created a classification based on Codman's original drawings [11]. In this fracture description system 5 fracture planes are combined, that render 12 proximal humerus fracture patterns, including two types of head-split fractures, that differ regarding perfusion of head fragments. The authors have also analyzed the predictors of humeral head ischemia after intracapsular fractures of the proximal humerus. The most relevant predictors of ischemia were the length of the dorsomedial metaphyseal extension, the integrity of the medial periostal hinge as well as the basic fracture pattern according to the binary description system [11]. In contrast to traditional believes, head split fractures alone are not synonymous with head ischemia or even AVN. Gavaskar et al. believe that the factors of risk for AVN include a complex fracture pattern, the presence of anterior dislocation, the associated soft tissue injury and the choice of the surgical approach (deltopectoral approach, used in the study for all anterior fracture-dislocations, has been shown to be associated with a higher incidence of AVN) [7]. Similarly, Ogawa et al. reported that the split head fragment in a posterior fracture-dislocation remained in good contact with an intact inferomedial attachment in 90% of the cases, and henceforth that the risk of AVN is low with head-splitting fractures associated with a posterior dislocation [22].
Another proximal humerus fracture description based on Codman was published in 2009 by Mora Guix et al. [16]. The authors locate head-split fractures in the 'Humeral head and cephaloglenoid group', characterized by 'articular surface fractures involvement' and describe them as follows: "The articular surface is fragmented into a number of separated pieces and at least 20% of the articular surface is affected".
All of the above-mentioned classifications are based on plain radiographs. Edelson et al. proposed a classification based on 3D CT reconstructions which achieved higher interobserver reliability than classification systems based on x-rays or 2D CT imaging [6]. The authors categorized head-split fractures as pertaining to 'the shield-fracture pattern' and described them as follows "most of the head is detached and driven backwards by the thrust of the glenoid. But, in this type, a part of the cartilaginous head is left attached to the shield fracture".
As a synopsis of all the currently available knowledge and based on our own clinical observations we propose the following classification system [27].
Type I - Head-split fracture with the fracture line within the posterior half of the humeral head with the larger head fragment located anteriorly (Figure 1)

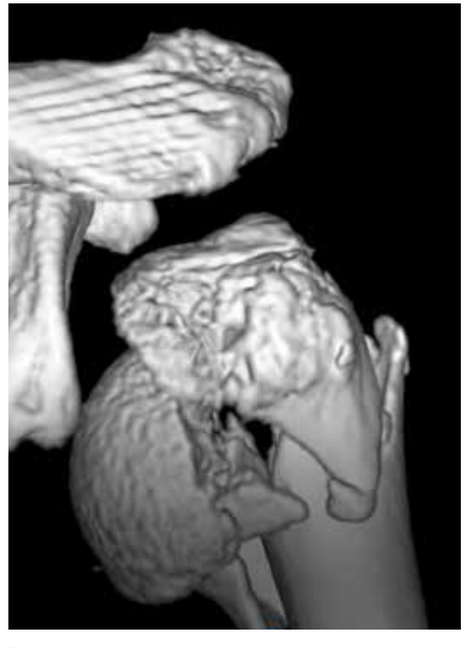

Figure 1
Head-split fracture type I with the fracture line within the posterior half of the humeral head with the larger head fragment located anteriorly

Type II – Head-split fracture with the fracture line within the anterior half of the humeral head with the larger head fragment located posteriorly (Figure 2)

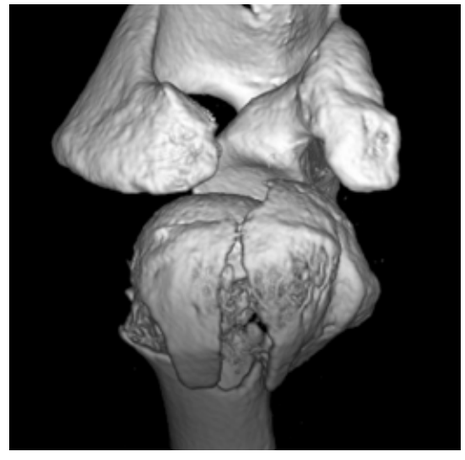

Figure 2
Head-split fracture type II with the fracture line within the anterior half of the humeral head with the larger head fragment located posteriorly

Type III Head-split fracture with a loose or free floating central fragment (Figure 3)

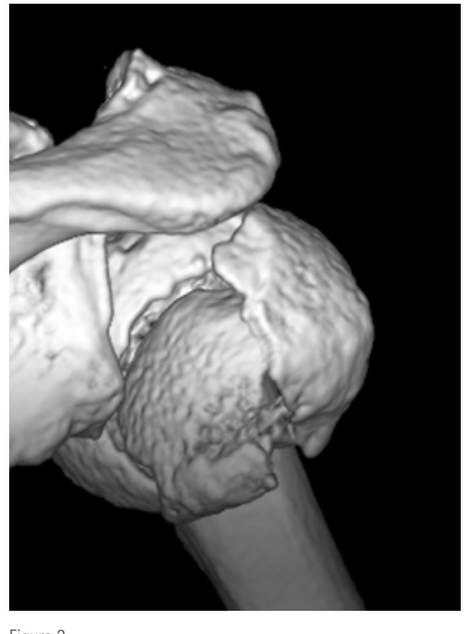

Figure 3
Head-split fracture type III with a loose or free-floating central fragment

Type IV Comminuted head-split fracture (Figure 4)

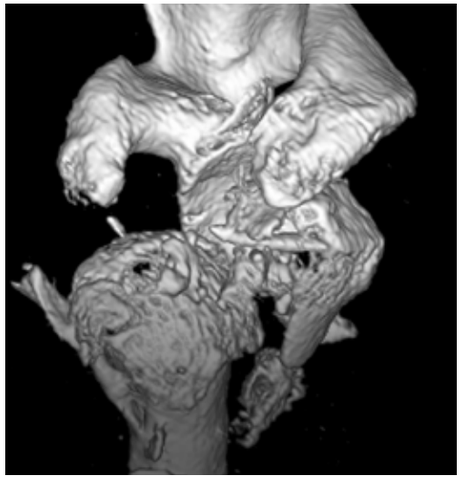

Figure 4
Head-split fracture type IV with comminution of the humeral head

CLINICAL EXAM

A careful clinical history including comorbidities, time and cause of injury, as well as previous shoulder function, complaints, or interventions is an important component of the assessment. Inspection can reveal extensive ecchymosis and swelling. Obvious deformity with visible changes of the shoulder contour due to shift of the humeral head in the anterior or posterior direction is suggestive of glenohumeral dislocation. The physical examination typically reveals tenderness of the upper arm and pain upon movement of the arm. A diligent neurovascular exam is crucial, with particular attention paid to axillary nerve function. Slow capillary refill, weak one-sided distal pulses, as well as paresthesias, numbness, and weakness are all warning signs of neurovascular injury. Although rare, acute neurovascular compromise may indicate the need for acute surgical intervention [20].

IMAGING

Generally standard radiographic imaging should include a true a/p-view and a Y-view. The Y-view helps to further determine the position of the humeral head in relation to the glenoid and shows posterior or postero-superior displacement of the greater tuberosity. If possible also an axillary view is recommended. An axillary view can not only identify a dislocation but is also helpful in determining involvement of the articular surface. However, the patient may be unable to tolerate the pain associated with the abduction of the arm which is necessary to obtain the axillary view. The Velpeau view may represent an adequate alternative in these cases.
Head-split fractures can often be identified by a double contour of the articular surface. Upon close examination in 87,5% of the cases the so-called pelican sign can be identified on a/p radiographs and sometimes also on axillary views [9]. The first arc represents the superior aspect of the greater tuberosity and the second arc a part of the articular surface which remained attached to the greater tuberosity resulting in a type I head-split fracture (Figure 5).

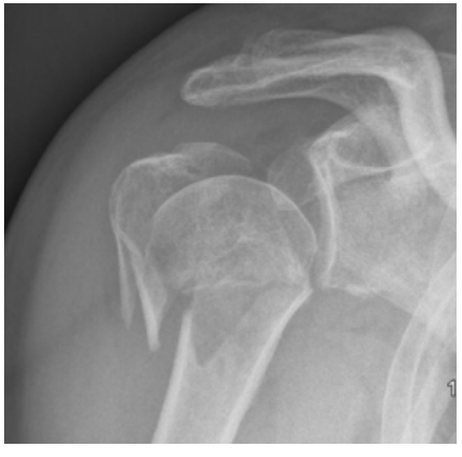

Figure 5
A/p radiograph of a head-split fracture type I showing the pelican sign at the greater tuberosity

If the pelican sign is detected on axillary views a type II head-split fracture is diagnosed. The first arc represents the lesser tuberosity and the second arc a part of the articular surface which remained attached to the lesser tuberosity (Figure 6).

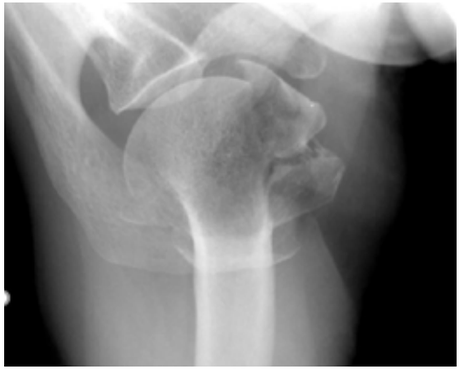

Figure 6
Axillary radiograph of a head-split fracture type II showing the pelican sign at the lesser tuberosity

Another line of increased bone density similar but lateral to the subchondral bone called the "trough line" as described by Cisternino et al. visible on a/p radiographs is suggestive of a large reverse Hill-Sachs lesion which is frequently encountered after posterior shoulder dislocations and is associated with non-displaced or displaced head-split fractures in approximately 24% of the cases [5,18]. Overlapping of the articular surfaces of the humeral head and the glenoid on a true ap-view indicates glenohumeral dislocation.
CT scan reconstruction should be obtained in all complex proximal humerus fractures in order to enable precise analysis of the fracture pattern [24]. CT, and especially 3D CT imaging, allows for better evaluation of the head-shaft relationship, tuberosity displacement, degree of comminution, and glenoid articular surface involvement and therefore facilitates the choice of treatment as well as surgical planning. The number of fragments in the setting of severe comminution is underestimated by standard radiography in >60% of cases [10]. Chesser et al. reported that especially head-split fractures can be difficult to recognize, and, when left untreated, poor outcomes can be expected [4]. Greiwe et al. reported that only 37,5% of the head-split fractures were identified on preoperative radiographs and 50% on computed tomography [9]. Magnetic resonance imaging (MRI) is rarely indicated in the setting of an acute injury. Only if a pathologic fracture due to primary or metastatic tumor is suspected MRI may be useful for staging of the disease.

TREATMENT OPTIONS

Preoperative classification and analysis of the pathomorphology as well as the likely compromise of vascular blood supply of proximal humeral fractures is mandatory for successful treatment.

Nonoperative Treatment

Non-displaced and minimally displaced head-split fractures may be treated conservatively including neutral brace or sling immobilization for three to four weeks with passive motion of the shoulder, followed by active-assisted range-of-motion exercises progressing to resisted strengthening at 3 months. However, there is no consensus on the threshold which distinguishes minimally displaced from displaced fractures in particular with regards to the intraarticular step formation. Displaced head-split fractures are usually not suitable for conservative treatment, however in some cases age and severe comorbidities impede surgery. In these cases malunion or nonunion of the fragments can lead to severe movement restriction, however many of these low-demand patients are satisfied with the residual function and benefit from generally low pain levels [23].

Operative Treatment

Joint-preserving management:
Closed reduction and percutaneous osteosynthesis should not be recommended since an anatomical reduction and stable reconstruction is difficult to achieve. An option for joint-preserving treatment of head-split fractures is open reduction and internal fixation using a locking plate and additional a/p screw fixation to stabilize the head-split (Figure 7a-b).

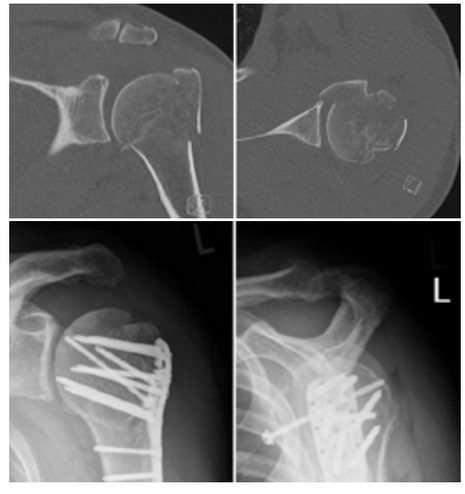

Figure 7
Displaced head-split fracture type II (a) and excellent radiological (b) outcome 2 years after open reduction and internal fixation

Gavaskar et al. report that ORIF using a locking plate achieves satisfactory results in simple head-splitting fractures [7]. Out of 15 patients under the age of 55 years 13 achieved bony union. At a mean follow-up of 34 months (25-47 months) no osteonecrosis or nonunion was seen in simple fractures (5 patients). In complex fractures (10 patients), head osteonecrosis was seen in 4 patients, nonunion in 2 patients, and posttraumatic early-onset osteoarthritis in 1 patient. Functional outcome scores showed significantly better results in simple fractures [7]. Chesser et al. describe good results with internal fixation (one or two cancellous screws) in simple head-splitting fractures in 3 of the 8 patients who were young (19-41 years) and opted for hemiarthroplasty in patients >55 years [4].
While improvement of surgical techniques and fixation devices may allow for adequate fragment reduction and retention, ischemia leading to AVN of single or multiple fragments of the humeral head remain a concern in the treatment of head-split fractures or complex proximal humerus fractures in general [11]. Robinson et al. investigated patients with complex proximal humerus fracture-

dislocations and divided them into two groups based on the integrity of soft tissue attachment and arterial backbleeding of the head fragment. After open reduction and plate osteosynthesis only two of 23 patients in the group with supposedly preserved vascular supply developed radiological evidence of osteonecrosis of the humeral head, compared to four of seven patients with complete soft tissue detachment and supposed compromise of vascular blood supply [26].
Due to the difficulty to exactly determine the extent of damage to the vascular blood supply of the head fragments and the existing chance of revascularization joint-preserving treatment is recommended in young patients regardless of the complexity of proximal humerus fractures including head-split fractures as long as acceptable reduction and sufficient stabilization of the fragments can be achieved [3].

Hemiarthroplasty

Primary arthroplasty must be considered in patients where a stable reduction due to severe comminution is not feasible considering the goal to avoid poor outcome and the necessity of a multiple revision surgeries after a failed osteosynthesis [14]. The decision to perform a primary shoulder arthroplasty should always be made on an individual basis and include patient specific factors as age, general health status, functional demand as well as pre-existing shoulder pathologies, including symptomatic glenohumeral osteoarthritis, or cuff-arthropathy (Figure 8a-b).

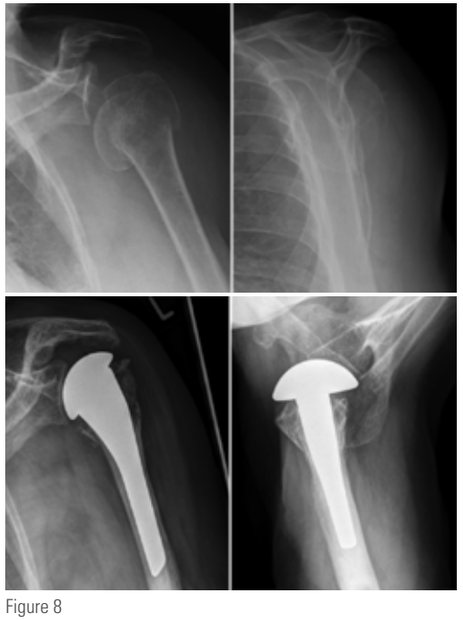

Figure 8
Displaced head-split fracture type II (a) treated with anatomical hemiarthroplasty (b)

Primary replacement of the humeral head in form of a hemiarthroplasty has been advocated for head-split fractures [15]. Antuña et al. reviewed 57 patients (44 women and 13 men, mean age 66 years) and evaluated the long-term outcome (minimum 5 years follow-up) of patients who underwent hemiarthroplasty as the treatment of a proximal humerus fracture. Seven patients had a 3-part fracture, 32 had a 4-part fracture, 4 had a 3-part fracture dislocation, 9 had a 4-part fracture and dislocation, and 5 had a head-splitting fracture. They report an average forward flexion of 146°±34° for patients with head-split fractures, which is better than for the other types of fractures (average of forward flexion 100°) but they do not offer an explanation [2]. Greiwe et al. compared the outcomes of hemiarthroplasty for head-split fractures (n=8, mean age 64 years) to those with standard 3- or 4- part fractures of the proximal humerus (n=22, mean age 68 years), and concluded that head-split fractures demonstrate improved range of motion with an average active forward flexion of 138°, complication rate of 12.5% and revision rate of 0% at an average 3.6 years follow-up compared with standard fractures with an average active forward flexion of 106°, complication rate of 36% and a revision rate of 14%. Despite these differences patient satisfaction, ASES and SST scores were not significantly different. The authors explain this unexpected discrepancy by the typically larger size and therefore better bone stock and healing potential of the tuberosities in the case of head-split fractures. They also refer that head-split factures may be technically easier to replace and allow a more accurate determination of the stem height [9].
Hemiarthroplasty should be preserved for the elderly patients due to the fact that results regarding function are often unpredictable and therefore associated with unsatisfactory results beside the eminent risk for young patients for loosening over time [29].

Reverse Total Shoulder Arthroplasty

Reverse total shoulder arthroplasty is reserved for patients with highly comminuted tuberosities, a pre-existing deficient or irreparable rotator cuff, or glenohumeral arthritis, as well as for elderly patients. With reverse shoulder arthroplasty, functional outcomes depend less on tuberosity healing and rotator cuff integrity, and patients have been observed to recover more quickly, with less requirement of careful protection and rehabilitation, than hemiarthroplasty patients [8]. Functional results are more predictable however, there are no studies referring to the use of reverse arthroplasty in head split fractures as a primary treatment.

COMPLICATIONS

Both, conservatively and surgically treated, head-split fractures can result in severe complications including malunion, non-union and AVN. Jost et al. reported that ten of eleven head-split fractures treated with locking plate osteosynthesis showed malunion at follow-up highlighting the general difficulty to achieve adequate reduction and stable retention of these fractures [12].
Gavaskar and Tummala state that most of their complications were seen in complex fracture patterns including a nonunion rate of 20% and AVN rate of 40%. They also reported one case of glenohumeral arthritis, one case of primary intra-articular screw placement, two cases of secondary articular screw penetration after AVN and secondary collapse and one patient with symptomatic impingement. Nonetheless, they recommended osteosynthesis in young patients, focusing on anatomic head and tuberosity reduction as well as bony union in order to provide a good bone stock for potentially necessary arthroplasty in the future [7].
Missed-diagnosis of head-split fractures can lead to severe complications. Chesser et al. described 3 cases of missed diagnosis that developed bony ankylosis and stiffness [4]. However, just one of them was unsatisfied due to pain, requiring a secondary surgical treatment. Spross et al. treated 7 head-split fractures with hemiarthroplasty and one with a locking plate, who developed a partial AVN but with no need for a revision surgery [30].

CONCLUSION

Due to the rarity of head-split fractures, limited evidence regarding the best choice of treatment is available in the literature. The goal of this review was to provide an overview on the existing knowledge. Delineate the exact pattern of the fracture with sophisticated imaging, will influence the individual patient specific procedure approach, not yet influenced by bone quality. The diagnostic process should include standardized imaging including radiographs and additional 3D CT imaging. A new classification of head-split fractures helps to better understand the pathomorphology and to select the appropriate surgical intervention. Despite a substantial complication rate joint preservation should be attempted in patients below the age of 50 years while older patients should be treated with prosthetic replacement due to the significant damage to the articular surface and potential loss of vascularity. Hemiarthroplasty for head-split fractures provides better functional results compared to classic three- and four-part fractures. Reversed shoulder arthroplasty seems favourable in cases with highly comminuted tuberosities, a deficient or irreparable rotator cuff, glenohumeral arthritis and risk of tuberosity nonunion as well as for elderly patients. Patients below the age of 60 years who are healthy and active may be treated with osteosynthesis as well. Conversely, patients with comorbidities and lower-demands may benefit more from arthroplasty.

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5/ AUGMENTATION OF PROXIMAL HUMERUS FRACTURES

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Proximal humerus fractures account for five to seven percent of all fractures.
The incidence in the elderly population, in patients over 65 years of age, as fragility fractures, is already on number four, following the one of spine, hip or distal radius fractures (Bell, 2011; D'Elia, 2010; Palvanen, 2006). The incidence of these fractures is growing with age, women being exposed two to three times more in comparison to men. These fractures are related to the degree of osteoporosis and may be already called as an indicator fracture for osteoporotic disease.

Most proximal humeral fractures may be treated by conservative techniques. Nevertheless, for displaced fractures open reduction internal fixation especially with plate osteosynthesis and angular stable screws from the lateral aspect is widely used. It was recently shown by a review from Gupta et al. that the clinical outcomes following open reduction and internal fixation are significantly better than following hemiarthroplasty and reversed total shoulder arthroplasty. However, ORIF had a significantly higher reoperation rate versus hemiarthroplasty and reverse total shoulder arthroplasty (Gupta,2014). Reoperations are mostly caused by complications and complications following ORIF are numerous. Sproul et al. have reviewed the literature to evaluate the short- and midterm functional results and the rate of common complications associated with the fixation of proximal humeral fractures with locking plates. They found the overall rate of complications being 49 % including varus malunion and 33 % excluding varus malunion, the reoperation rate being 14 %. The most common complication was varus malunion with 16 %, followed by avascular necrosis accounting for 10 % and screw perforation for 8 % (Sproul,2011). The combination of varus displacement, avascular necrosis and screw perforation into the glenoid is one of the most devastating ones and a new complication by this type of osteosynthesis. However, treating these complex three- and four-part fractures in the elderly population non-surgically high complication rates may be found as well. Iyengar et al. found 40 % complications including 23 % varus malunion and 14 % avascular necrosis concerning only 3- and 4-part fractures in contrast to a relatively lower rate of complications including all type of fractures (Iyengar, 2011). By several publications, it was shown that complications are highly related with risk factors. These risk factors are mainly female gender and a higher age over 65 years, the reduced local bone mineral density especially in elderly females, the missing medial support of the head fragment responsible for recurrent. varus malposition, the length of the medial head extension and displacement of the medial calcar, being a risk factor for reduced vascular supply or even the quality and displacement of the tuberosities (Krappinger,2011; Hertel, 2004; Kralinger,2009). Recognizing these risk factors being responsible for an increased rate for complications and in consequence altering the surgical technique was shown to significantly reduce the rate of secondary screw cutout (Spross,2012). Altering the surgical technique and using an adequate technique for this kind of difficult and complex fractures includes several different aspects. First, it is the selective indication. If the indication for open reduction internal fixation is given an anatomical reduction and stable fixation is among the most important prerequisites for a good outcome and a reduced rate of complications. There are several technical aspects that have been shown to reduce secondary displacement of the fracture. Among them being the reconstruction of the medial support, the number of head screws or the medial support screw. Especially the medial support screw was shown to significantly reduce screw perforation and failure rate (Zang,2011). Double plating with an anterior supporting additional plate may increase the stiffness of the reconstruction (Little,2014). Another aspect to increase the stiffness of the reconstruction are different augmentation techniques. Three options of augmentation are available, all of them have been shown to be effective biomechanically and clinically as well to reduce the amount of secondary displacement and secondary screw cutout.

Filling the void

In severely impacted valgus proximal humeral fractures, by impaction of the head fragment the spongeous bone in the metaphysis is compressed and following reduction a void is created that may not be filled sufficiently by the reduced tuberosities. Robinson (Robinson, 2003) was the first to show that by filling the void with calciumphosphate cement all reductions could be maintained without

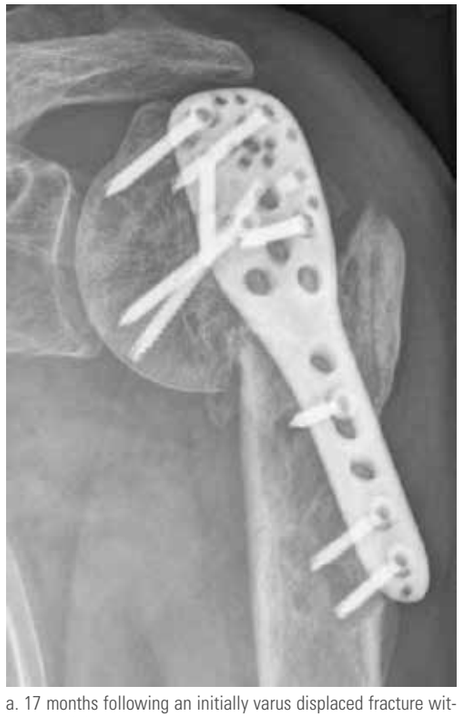
avascular necrosis. He had a complication rate of 24 % without reoperation and a Constant Score of 80 points. Egol at al., comparing void filling with cancellous chips, calciumphosphate cement or no augmentation showed a decreased fracture settling and significantly decreased intraarticular screw penetration rate in the calciumphosphate cement augmented group versus non-augmentation or augmentation with cancellous chips (Egol, 2012). Filling the void with autologous bone or with allograft as well has clinically shown favorable outcomes. In that way Kim, filling the void with bicortical impaction grafts did not observe a varus collapse or hardware related complications (Kim,2012). Euler at al., using cancellous allograft transplants in high risk noncompliant patients could show a high rate of healing with allograft incorporation with no significant loss of reduction or evidence or avascular necrosis of the humeral head (Euler, 2015).

Screw tip augmentation

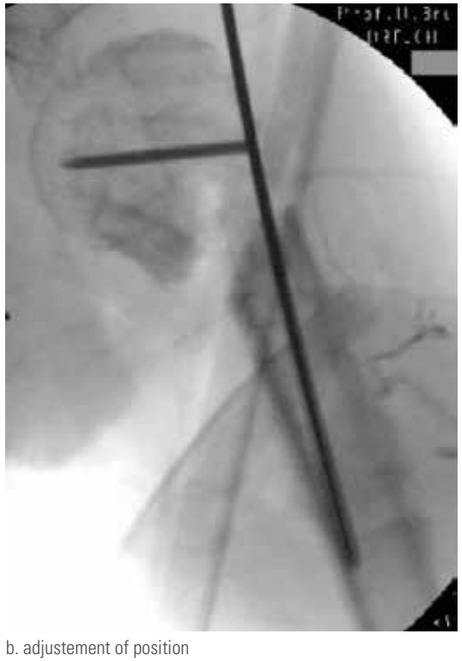
Screw tip augmentation by PMMA cement could be shown experimentally to enhance the implant screw anchorage in the humeral head. The improvement of screw purchase was increasing with decreasing bone mineral density. Further the motion at the bone implant interface was reduced (Unger, 2012; Schliemann,2015). The literature on the clinical effectiveness of screw tip augmentation is still sparse. Katthagen et al. showed significantly reduced loss of reduction in the augmented group in comparison to the control group. However, they reported an increased AVN rate in the augmented group by 8 % (Katthagen,2018).

Strut graft augmentation

The third option to increase stiffness is strut graft augmentation. Experimentally either allogenic or autogenic graft augmentation was shown to significantly increase both the maximum failure load and the initial stiffness (Bae 2011) of the construct and it was shown to be especially useful when there is a medial comminution (Osterhoff,2011). Clinically for nun-unions strut graft augmentation was shown to be effective to achieve stable fixation and union by G. Walch, showing a 96 % healing rate without AVN and a significant increase of the Constant Score (Walch,1996). (Figure 1).



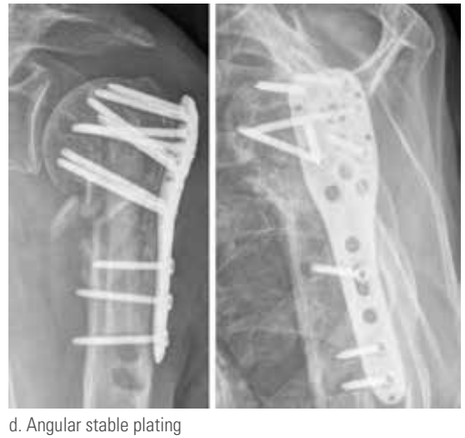
a. 17 months following an initially varus displaced fracture without medial support



b. adjustement of position

Figure 1
Allo-strut graft augmentation for a non union of a 64 year old female patient

c. Allo strut graft augmentation



d. Angular stable plating

If, in acute proximal humeral fractures this technique can be effective as well, reduce the complications and in consequence the reoperation rate and lead to acceptable outcomes, was looked for in a systematic review by Saltzman et al. The screw penetration rate in this review was shown to be as low as 3 7 % with a 99. 25% healing rate in 136 patients with a follow up rate of 20 months (Saltzman,2016). To compare the effectiveness of strut graft augmentation in osteosynthesis in geriatric proximal humeral fractures Hinds et al. compared two groups of nongeriatric proximal humeral fracture patients treated via locked plating with endosteal fibular strut allograft augmentation with a nongeriatric group treated with the same principals. There were no significant differences in functional scores, radiographic outcomes, or complication rates between the 2 cohorts, although in 1 geriatric patient, osteonecrosis developed and screw penetration through the collapsed head was present 3 years after surgery (Hinds,2015). They concluded that osteosynthesis of proximal humeral fractures via looked plating with fibular strut allograft augmentation showed similar results between geriatric and nongeriatric patients. In a level III prospective and controlled study for comparison of intramedullary fibular allograft with locking compression plate versus shoulder hemi-arthroplasty for repair of osteoporotic four-part proximal humerus fractures, Constant and DASH scores, activities of daily living (ADL), and range of motion (ROM) were statistically higher in the strut graft / ORIF group than those in the hemiarthroplasty group, whereas the pain scores were obviously lower than that in the hemiarthroplasty group (Chen,2016).

In conclusion augmentation with different techniques has shown experimentally and clinically proven results. “Filling the void” is indicated with intact medial support. Hydroxyapatite, different forms of bone cement or allograft or autogenous bone grafts may help to support the head fragment and avoid secondary displacement.

Screw tip augmentation is experimentally well established but clinically still has little reports in the literature. It is probably as well indicated with intact medial support. Intraoperatively a perfect reduction is a prerequisite condition for success.

Strut graft augmentation is the technique which leads to the highest degree of stiffness. In the literature its effectiveness is documented as well for non-unions as for acute fractures in the high-risk type of geriatric fractures. By that the indication for open reduction internal fixation may be extended to these difficult fractures by avoiding complications. However, fracture settling, or the degree of avascular necrosis may not be influenced significantly.

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6/ INTRAMEDULLARY NAILING - A PRACTICAL GUIDE

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INTRODUCTION

Approximately 10-20% of all proximal humerus fractures (PHF) require open reduction and internal fixation (ORIF) [1], with two goals: to achieve primary fracture stability and to allow for early mobilization of the shoulder [2, 3]. The AO organization stated that at least one screw must be perpendicular to the fracture line. But, looking at most of the systems of osteosynthesis available on the market, only few respects that rule for PHF, especially plates and most of the intramedullary nails (IMN). Their screws have almost a latero-medial axis, parallel to the fracture line, fixing the humeral head without fixing properly the tuberosities. But it has been clearly demonstrated that the success of an ORIF of a proximal humerus fracture lies on the greater tuberosity status [4].
For complex PHF, we prefer IMN for biomechanical considerations (improve the pullout strength of the screws inserted in a divergent manner by shortening the lever arm) and quality of tuberosities fixation perpendicular to the fracture line, even for osteopenic patients [5, 6].

SURGICAL TECHNIQUE

Description of the nail [5]

The Aequalis Nail (TORNIER, SA) is a straight nail with a length of 130 mm (figure 1). It has basically 4 proximal divergent interlocking screws: the1st Screw (Greater Tuberosity) will be 130º from the AP screw i.e. the 2nd Screw (AP Screw, Lesser Tuberosity), the 3rd Screw (Greater Tuberosity) will be 150º from the AP Screw. The 4th Screw is an optional screw directed to the calcar of the humerus: (Head Support) and will be 95º from the AP Screw. Distally 2 divergent screws of 20° lock the nail. The external jig of this nail is dedicated first to target screw positioning through the proximal and distal nail and also to restore 20° of retroversion of the proximal humerus epiphysis by aligning a pin inserted in the jig with the forearm with the elbow flexed at 90°.

Patient positioning

Surgery is performed with the patient under general anesthesia with an interscalene brachial plexus block. Patients are in beach chair position (Fig.1).

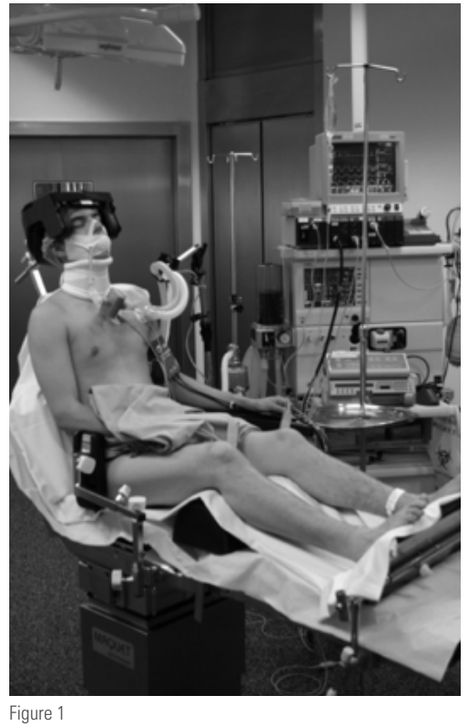

Figure 1

The fluoroscopic C-arm must be placed first in AP-view. The patient's arm must be completely free for any movement in any direction, especially in rotation to help the reduction of the surgical neck fracture line.

Procedure

A transdeltoid approach is necessary for complex fractures (between the anterior and mid-deltoid), but a percutaneous nail insertion remains an option for surgical neck fractures. One must understand that in retropulsion the humeral head anteriorly related to the anterior acromion. After evacuation of the sub-acromial hematoma, and bursectomy, the first step of this surgery is to control tuberosities and put sutures through the cuff to control all fragments (Fig. 2).

Figure 2

One must keep in mind that the greater tubersosity is almost always displaced posteriorly and inferiorly. This maneuver also helps the surgeon to figure out how to obtain adequate reduction. This also allows the surgeon to perform a tenotomy / tenodesis of the biceps through the rotator interval. Using an elevator, the humeral head is reduced relatively to the glenoid fossa and related to the medial hinge. The calcar must be reconstructed ; this is of paramount importance.

Through this split, the site of the nail entry point is determined, posterior to the bicipital groove, medial to the supra-spinatus footprint, in the cartilaginous zone of the top of the humeral head (about 1.5 cm medial to the most medial edge of the greater tuberosity). In case of a valgus or varus impacted fracture, a transitory fixation of the humeral head to the glenoid might be necessary, always keeping the medial edge continuous (fig. 3).

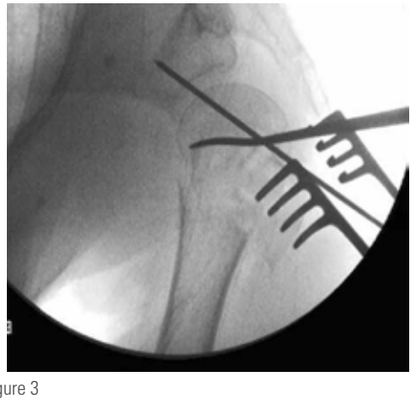

Figure 3

After developing the entry point, the guidewire is passed across the fracture site into the humeral canal under fluoroscopic control. The nail is then inserted until the end of the nail lies beyond the articular surface at the apex of the humeral head (fig. 4).

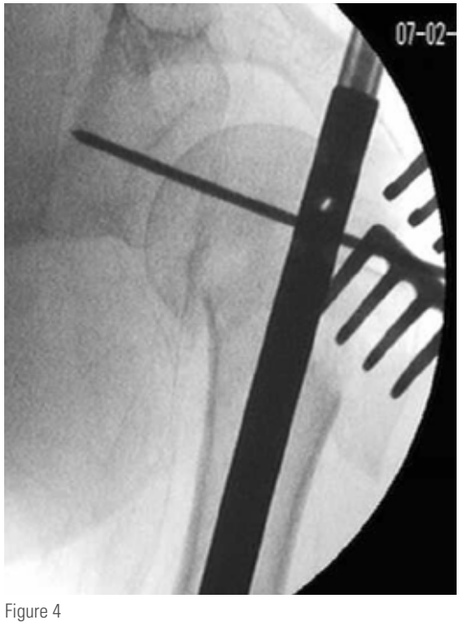

Figure 4

Then tuberosities are reduced with respect to the head and shaft and fixed with the proximal screws (fig. 5 and fig. 6).

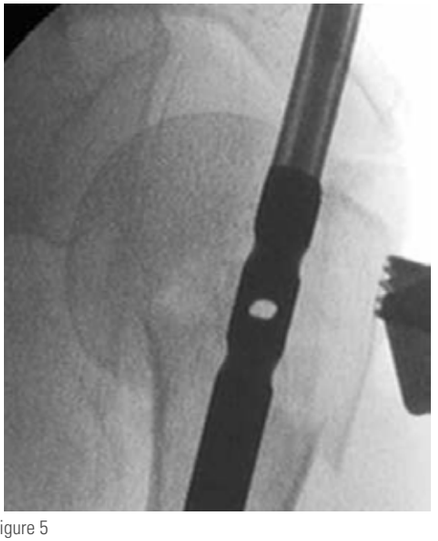

Figure 5

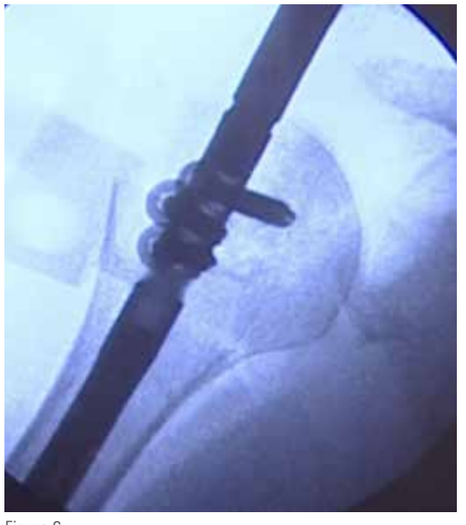

Figure 6

The number of proximal screws depend on the number of fragments: 2 perpendicular for surgical neck fractures and 3 for four-part fractures (2 in the greater tuberosity and 1 in the lesser tuberosity). The calcar screw remains exceptional in our experience. Whenever possible, sutures are used for a complementary ostéosuture of the tuberosities to neutralize the pull of the rotator cuff. Finally, distal screws are inserted through 2 skin punctures. In this case those screws are divergent to prevent any nail micromotion.

Specificities for two-part fractures

Distal fixation must be obtained first. Then, gentle retrograde impaction of the distal to proximal segment via a sliding slap hammer is necessary ("back-slap" hammering) to improve intraoperative compression of the fracture. Afterward, proximal screws fixation can be achieved by 2 screws (2 posterior screws or 1 anterior and 1 posterior).

Post-operative patient care

The shoulder was placed in a sling for 2 to 4 weeks postoperatively, but patients are asked to mobilize passively their shoulder mobilization with pendulum exercises immediately. Depending their pain level patients are also encouraged to perform light activities of daily living as soon as possible. Strengthening is allowed at 6 weeks postoperatively.

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7/ VIRTUAL REALITY: THE FUTURE OF SURGICAL EDUCATION IN ORTHOPEDICS AND BEYOND

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INTRODUCTION

Virtual Reality (VR) has expanded from the entertainment industry to clinical medicine in the preceding decades based on VR's unique ability to replicate scenarios and environments while teaching skills in a cost-effective manner. The current VR standard utilizes a combination of equipment including a three-dimensional (3D) rendering capable computer, head mounted display (HMD) and controllers with position trackers. These work to create an immersive, interactive, and multisensory environment.[1] Increasingly common is the addition of haptic feedback to VR to recreate sense of touch, vibration and motion.[2,3] Unfortunately, there exists a discrepancy between available products for orthopaedic surgeons and those available to other industries, as clinical medicine has lagged behind adoption of contemporary VR. The term virtual reality has been loosely applied to available products for orthopaedic surgery in both low, and high-fidelity formats. Both low and high-fidelity formats suffer from task specificity and limited use, and available content or commands relating to interactivity.[4] The limits of fidelity designations lead VR to remain ill-defined in the orthopaedic literature, with products lacking immersion available to other industries including automotive, aerospace, consumer entertainment, and tourism.

VR has been utilized in preoperative planning, intra-operative adjuncts, as well as surgical simulation for education purposes. VR in orthopaedics has demonstrated greatest focus and potential in application for education secondary to its demonstrated face, construct, content, and transfer validity.[4] Surgical training has been progressively scrutinized over validity of traditional teaching methods and has suffered from reduction of working hours to trainees throughout the US and Europe[5,6] VR provides an experiential learning cycle ad infinitum.[7] It is because of these reasons that orthopaedic training committees and organizations around the world including American Academy of Orthopaedic Surgeons (AAOS), American College of Surgeons, and Haute Autorité de Santé in France endorse surgical simulation.[8]

Figure 1
Immersive virtual reality (VR) system demonstrating head mounted display (HMD) with controllers by PrecisionOS Technology (PrecisionOS Technology, Vancouver, Canada).

CURRENT VR USES

Preoperative Planning

The AO group emphasizes pre-operative planning of fracture care as essential in achieving successful reduction and fixation.[9] Classic reduction planning remains time-consuming, cumbersome, difficult with increasing degrees of comminution, and does not relate soft tissue effects and most efficient reduction pathways based on these soft tissues. 3D reconstructive software has been produced to aid in reduction, with publications pertaining to shoulder surgery focusing on proximal humerus fractures. A thorough review of computer-assisted pre-operative planning demonstrates the complexity of computational prowess and expert surgical involvement required to produce a usable model. Jiménez-Delgado et al. note pre-operative planning consisting of generation of bone fragments, virtual reduction planning, and analysis of a virtual reduction plan. [10,11] The complexity of fracture, interplay of soft-tissues, and reduction pathways of proximal humerus fractures lends to VR integration and more advanced 3D analysis. Harders et al. developed a virtual environment consisting of simulated interactive assembly of multi-fragment proximal humerus fractures including haptic sensors and demonstrated usability as a pilot study in four clinical scenarios. Subsequent to this work, Fürnstahl et al. developed a semi-automated fracture reduction virtual environment for proximal humerus fractures based on four cadaver specimens and tested on four clinical cases with contralateral uninjured humerus for comparison with small technical error rates[12] Bicknell et al. produced a pre- and intra-operative system for pre-operative planning and intra-operative guidance for 4-part proximal humerus fractures managed with hemiarthroplasty. Though underpowered, the system allowed for treatment of simulated 4-part proximal humerus fractures, restoring patient-specific anatomy with pre-operative CT scans and intra-operative navigation compared to traditional reduction maneuvers.[13]

Figure 2
Immersive VR demonstrating interactive preoperative planning and fracture reduction software using proprietary PrecisionOS Technology platform

These initial systems, though promising in concept, lack experimental rigor and level of evidence, power, feasibility and availability, and clinical correlation to real operative scenarios. It has been over a decade since the publication of these works, with no published improvements or clinical applications despite significant improvement in commercially available computing and technology. Currently available systems utilize plain films and CT scans for 2D or 3D reconstructions for templating through commercially available fixation systems but are non-immersive. There is no published evidence regarding validity, efficacy, or translation of these products to clinical scenarios. There exists a large opportunity for development, validation, and application of immersive VR systems for trauma pertaining to the shoulder.

Elective: Shoulder Arthroplasty

Clinical studies have demonstrated implant malposition correlating with implant failure in TSA and reduced functional range of motion. Implantation errors of version or inclination greater than 10 degrees or offset errors greater than 4mm can significantly contribute to the incidence of TSA failure.[14] Ideal position to prevent failure is less clear in rTSA, though malposition of the glenosphere may impart scapular notching leading to worse patient outcomes. Standard radiographs and 2D CT scans may overestimate glenoid wear and retroversion.[15] Walch et al note glenoid retroversion, inclination, and humeral head subluxation as inferiorly characterized by 2D CT imaging and axillary radiographs compared to 3D CT reconstruction, though note potential difficulty in obtaining these due to manual segmentation required. In their in vitro study utilizing pre-operative 3D templating and patient specific implants (PSI), their final constructs of 18 scapula demonstrated reliability and precision of this technique.[16] The available systems for pre-operative planning of TSA and rTSA are interactive though largely single function and non-immersive. There has not been noted or demonstrated effectiveness of VR systems on training of shoulder arthroplasty or glenoid preparation and pre-operative assessment of patient specific anatomy.

Figure 3
Preoperative templating of glenoid component utilizing immersive VR and soft tissue subtraction using the PrecisionOS Technology platform

Intra-operative

Advances in computing technology and available HMD have lent for development of AR systems to aid in fracture management and percutaneous fixation. Classic orthopaedic fixation strategies require intra-operative fluoroscopy utilizing a C-arm. Conversion of snapshots in 2D referencing to 3D scenarios suffer from projective simplification and are error prone, even in hands of expert surgeons. Proposed and studied examples include intra-operative cone-beam CT (CBCT) with use of an RGB-D (RGB plus Depth) camera, registration of pre-operative CT to intra-operative fluoroscopic image, or external navigation tracking systems. Further advances include co-calibrated C-arm system to see-through HMD. Goals of future work include reduction of set-up time, ease of use, and accurate localization of real-time surgical site information to pre-operative imaging data.[17,18] These systems have been utilized on sacroiliac screw placement, intramedullary nail placement, as well as pedicle screw insertion in spinal surgery, though there is no current evidence pertaining to shoulder surgery.[17,18]

Surgical navigation in total shoulder arthroplasty and PSI has been shown to improve glenoid positioning in three prospective RCTs and one prospective non-randomized study.[16,19,20,21] Furthermore, a recent pooled meta-anlysis of surgical navigation and PSI in total shoulder arthroplasty has demonstrated superiority of these modalities for glenoid positioning in TSA, though long term study

and clinical correlates are currently lacking.[14] Navigation is labor intensive and suffers from increased procedural time, estimated at 31 minutes per case, as well as up to 37.5% abandonment due to system registration errors.[20,19] There has been no published utilization of AR in glenoid positioning during TSA or rTSA, though the theoretic benefits of determining glenoid version and visualization of the entire scapula during glenoid component placement are apparent.

Surgical Training and Simulation

Simulation is currently defined in medical literature as "any technology or process that recreates a contextual background in a way that allows a learner to experience mistakes and receive feedback in a safe environment."[6] There appears to be over 60 available VR products quoted in the literature relating to assessments of validity.[4] Six of these products are related to shoulder arthroscopy, namely ArthroMentor/Insight Arthro (Simbionix, Airport City, Israel), Alex Shoulder Professor (Sawbones Europe, Malmo, Sweden), Procedicus arthroscopy (Mentice Corp, Gothenburg, Sweden), ArthroS (Virtamed, Zurich, Switzerland), ArthroS (Virtamed, Zurich, Switzerland), and insightMIST (3D Systems, Rock Hill, South Carolina). Two products were seen to involve general arthroscopy skill training, namely Swemac/Augmented Reality Systems (Swemac, Linköping, Sweden), and Virtual Reality Tetris Game Using Arthroscopy (VirtaMed, Zurich, Switzerland). Available studies include small sample sizes, the largest of which was seen to have an n=78 in a study by Pedowitz et al.[22] Levels of evidence range from 1b to 4 by EAES standards. Rebolledo et al. demonstrated improved performance of eight PGY1-2 compared to control group of six PGY1-2 in arthroscopic time to task completion and number of iatrogenic injuries following 2.5 hours of arthroscopy simulation.[23] Waterman et al. in their comparison of 12 orthopaedic trainees receiving repeated scheduled simulation sessions over a 3 month period versus a cohort of 10 similar trainees receiving only a single training session had significantly improved Arthroscopic Surgery Skill Evaluation Tool (ASSET) scores.[24] Banaszek et al. performed an RCT with outcomes of Global Rating Scale (GRS) score, arthroscopic checklist, and procedural time on fresh-frozen cadavers demonstrating improved performance of VR population over benchtop simulator control group in GRS scores, and had higher ratres of completion of a "surprise task", demonstrating transfer of skill.[25] Yari et al. demonstrated composite improvement for junior and senior residents in shoulder arthroscopy on the ArthroS simulator system given repeated series of training modules.[26] Given the demonstrated improvement in arthroscopic skills demonstrated by learners, Rahm et al. determined via ASSET score that for PGY0-5, 3-5 hours of arthroscopic VR use significantly improves camera handling, anatomy, and triangulation.[27] Given the number of publications and varying systems used, there exists significant heterogeneity between studies to preclude pooled meta-analyses.[28]

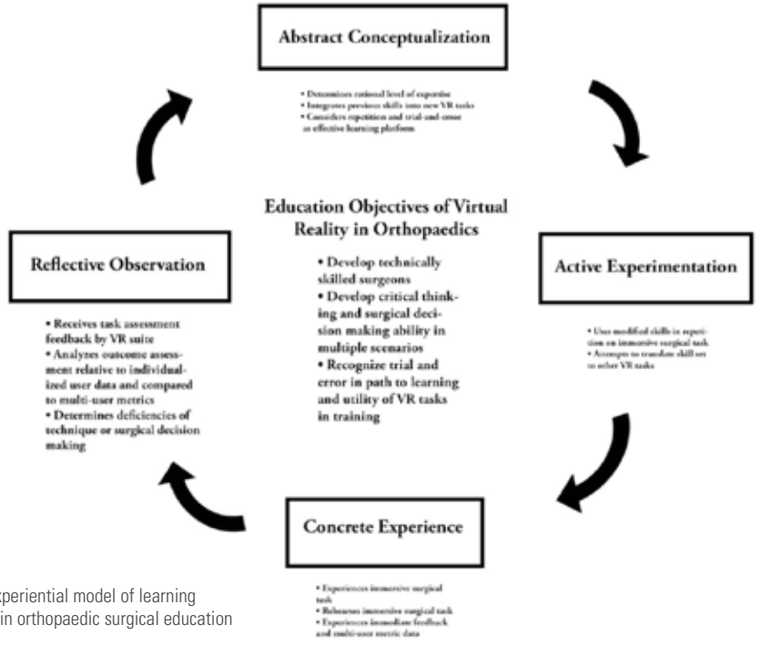

Figure 4
Proposed experiential model of learning utilizing VR in orthopaedic surgical education

Figure 5
Immersive VR system utilizing the PrecisionOS Technology platform to practice simulations of total shoulder arthroplasty, specifically challenges of glenoid exposure and implant positioning

There are no current VR systems published in the literature to practice other aspects of shoulder surgery, including arthroplasty. Furthermore, as real surgical practice combines technical skill with decision making, the available VR systems lack decision making scenarios to learn from errors and other real-life components including consent processes, effective communication, leadership, and consideration of surgical or non-operative alternatives. These transferrable skills are reflected in the Canadian orthopaedic training requirements put forth by the Royal College of Physicians and Surgeons of Canada, responsible for licencing and accreditation.

SUMMARY AND RECOMMENDATIONS

VR in orthopaedics continues to lag behind other surgical specialties and industries. Shoulder surgery offers potential advancement of immersive VR in regard to pre-operative planning, intra-operative utilization, and for simulation and instructional purposes. Recommendations for product development include emphasis on creating and validating immersive VR systems capable of realism and multiple scenario use including that of cognitive simulation and decision making. These systems should additionally aim to be portable, easy to use, cost-effective and present a secure network infrastructure for adaptive user generated content. Following development, these products should be validated on current EAES standards, explicitly stating methods of validity with focus on transfer validity to real life scenarios as well as reliability metrics. There should additionally be demonstrable reality and immersion validity assessments as is common in other industries. Higher level evidence for translation of immersive VR including improved technical outcomes, hardware utilization and wasted hardware, time-action analysis, or patient derived outcomes should be pursued. For simulation purposes, immersive VR allows repeated and consistent training and could improve upon the current ad hoc clinical scenarios and remove ethics of patient interaction. Current systematic reviews highlight lack of evidence regarding transfer of skills, patient derived outcome measures, or cost-effectiveness for surgical simulation based on non-immersive VR. Though currently not demonstrated in the literature, immersive VR has the potential to stimulate cognitive pathways with task specific modules and has the added ability of physical rendering of realistic operative scenarios.

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8/ RECENT AND FUTURE INNOVATIONS IN SHOULDER ARTHROPLASTY

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INTRODUCTION

Since its first description in 1893 by Péan1 and its later generalization in the 1970s by Charles Neer2, shoulder arthroplasty has evolved a lot. In 1987 shoulder arthroplasty even more when Paul Grammont described the first reverse shoulder arthroplasty3. Nowadays, both anatomic total shoulder arthroplasties (TSA) and reverse shoulder arthroplasties (RSA) are implanted depending mostly on the status of the cuff4 and on the shape of the glenoid5.
These two groups of implants have been proven to lead to excellent functional outcomes when used in the appropriate indications: TSA is the treatment of choice for end-stage glenohumeral arthritis6 and RSA is the treatment of choice for glenohumeral arthritis with a dysfunctional rotator cuff7.
Although these arthroplasties provide predictable return to function and pain relief, they are not perfect and complications exist8. Surgeons and implant manufacturers keep proposing innovations to attempt to reduce these. Some of these innovations lie in the design of the implant itself, others in improvements in the positioning of the implant.
The most common reason for failure and revision of a shoulder arthroplasty is the failure of the glenoid component9. This is especially true in cases where severe glenoid retroversion leads to changed anatomy of the glenoid with limited exposure to the glenoid and modified anatomic landmarks. Additionally, in these cases, poor glenoid bone stock forbids excessive asymmetric reaming10.

Recent improvements in the design of the implant.

Recently, augmented glenoid implants have been proposed. These require minimal bone removal, correct pathologic version, restore the joint line, and are biomechanically stable with physiologic loads11. These have been shown to give satisfactory short-term clinical results in both TSAs and RSAs12, 13.
New bearing surfaces have also been proposed recently. Pyrolytic carbon more commonly called "pyrocarbon" has been described in shoulder hemiarthroplasty especially in younger patients. This highly biocompatible surface has a very low coefficient of friction and Young modulus similar to that of cortical bone14. Therefore, it has been hypothesized that this bearing surface used in shoulder hemiarthroplasty would not erode the glenoid bone as much as a metallic head. However, clinical results have not yet been published.
Other recent design innovations have been proposed to facilitate revisions. These include the use of short-stemmed or stemless humeral implants15, 16 and the use of platform convertible stems although these have been described as early as 200317.

Recent improvement in the positioning of the implant.

Although all these improvements in the design of the implants appear to be interesting, they do not dramatically modify our understanding of shoulder arthroplasty nor do they modify dramatically functional outcomes. Implant positioning and especially glenoid component positioning is critical to the longevity and the function of shoulder arthroplasty. When placed eccentrically, humeral head may no longer articulate with the center of the glenoid component. With active motion, glenohumeral translations may then lead to eccentric loading and a rocking horse effect10. Repetitive eccentric loading can then lead to glenoid loosening and early failure of the glenoid component18.
Clinically, glenoid components have been shown to survive longer when placed in the neutral version.4 In the setting of RSA, incorrect baseplate placement and fixation in the scapula can lead to early catastrophic failure, instability and scapular notching which may cause secondary implant loosening and functional decline19. Component placement has been shown to be variable between surgeons and even within a single experienced surgeon's practice with modern instrumentation.8 Recently the accuracy of glenoid component placement has been improved by the development of preoperative planning on three-dimensional reconstructions of shoulder CT scans20-22. Important advances have been made regarding preoperative planning and it is now possible to predict intraoperative difficulties ahead of the surgery and to simulate the ideal positioning of the implant preoperatively. Further innovations now allow the surgeon to determine the pre-osteoarthritic morphology of

the glenoid using either patient-matched contralateral non-diseased scapulae or using the so-called glenoid vault model23. Several studies have now clearly shown that positioning of the glenoid implant was improved by preoperative planning20, 21. Once it has been possible to accurately plan the implantation of the glenoid component, researchers have focused on determining ways to reproduce reliably the plan during surgery. Several techniques have been proposed. These include : (1)infrared or electromagnetic or augmented-reality technologies that can be used for intraoperative real-time feedback, (2)patient-specific guides, (3)surgical simulators used for teaching and allowing the user to practice repeatedly. Several studies have proven that intraoperative navigation lead to more accurate placement and more reliable results in both TSAs24-27 and RSAs28 and it also appears that navigation is a valuable tool for education and for the improvement of surgical skills. However, these techniques use a cumbersome intraoperative tracking system and an interesting alternative could be the use of simpler patient-specific guides. These are custom-made jigs which allow precise positioning of the central guide pin, control of the depth of reaming and precise guiding of the screws to obtain the best possible purchase and to prevent eventual impingement with the suprascapular nerve. These have been proven to improve glenoid positioning in both cadaveric and in clinical studies27, 29-32. However, it remains still unknown whether the use of such guides is associated with improved clinical outcomes.

Future improvements in the positioning of the implant.

Therefore, very powerful tools are now available which allow the surgeon to plan very precisely the implantation of the glenoid component and more rarely of the humeral component. Devices have been developed in order to reproduce in a precise and reliable fashion this preoperative plan during surgery. However, a very important question remains: what is the optimal position of the implant? Although the position allowing the best fixation in the scapular bone appears to be quite clear (congruent osseous backside support of greater than 90% of the implant surface, full bony containment of the central peg or keel, least amount of reaming), the ideal position to obtain optimal function depends of many unknown parameters and is still unclear.

In the setting of TSA, it appears logical to recreate the original pre-osteoarthritic anatomy. However, in cases of severe osteoarthritis with an important medialization of the joint line, it remains unknown how exactly should the joint line be restored. Indeed, restoring the pre-osteoarthritic anatomy could lead in these patients with important soft-tissue contractures to an overstuffing of the joint which could in turn lead to a painful stiff shoulder with early polyethylene wear and early glenoid loosening. This is even more true in the setting of RSA where even the pre-osteoarthritic anatomy cannot be used as a landmark as the very biomechanical principle of the RSA lies on modifying completely the anatomy of the shoulder. However, it remains still unclear whether the original recommendations by Grammont (155° neck shaft angle, center of rotation at the bone-implant interface, medialization and lowering of the humerus) lead to the best functional result possible and whether these recommendations should be applied regardless of the patient's anatomy. Indeed, it has been shown by Boileau and Walch33 that the diameter of humeral heads varies between 37 and 54 mm. This implies a different tension of the remaining rotator cuff and of the soft tissue around the glenohumeral joint which should probably be incorporated in our planning and that should probably be restored postoperatively. This optimal position might also vary depending on the rotator cuff muscles which are left. Similarly, the tension of the deltoid varies depending on several factors: lowering of the deltoid insertion, lateralization of the greater tuberosity, deltoid volume and quality of the deltoid muscle. Precise evaluation of these factors and the way in which each of these influence the final functional outcome remain for the most completely unknown. However, it is unlikely that a perfect standard configuration of the prosthesis components can be generally recommended. Therefore, in the setting of RSA, the optimal amount of medialization/lateralization/distalization/inferior tilt is still unknown. In addition, most of the work on planning, navigation and patient-specific implants has concerned the glenoid component as most complications took place on the glenoid side. However, the tension of the soft tissue (deltoid, rotator cuff and capsule) on which relies the postoperative function and the risk of instability depends almost exclusively on the version and on the medio-lateral and proximo-distal position of the humeral stem. Finally, most of our knowledge on implant positioning comes from standard anteroposterior radiographs in the standing position which take into account the resting position of the scapula and therefore takes into consideration the scapula-thoracic motion. Today, none of the planning and navigation systems commercially available incorporate scapulo-thoracic motion!

In summary, great progress has been made recently in the understanding of the positioning of shoulder implants. These recent progresses have enabled us to place our components (especially glenoid components) in a predictable and reliable fashion. Therefore, we are now able to place a glenoid implant very accurately in a very precise position decided preoperatively. But, we still do not know clearly the precise position we should be aiming for.

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9/ HOW TO DEAL WITH FAILURES OF NON-OPERATIVE TREATMENT?

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INTRODUCTION

There two types of failed proximal humerus fracture after non-operative treatment: nonunion and malunion. The rate of nonunion is estimated to be 1.1% to 10%[11] following closed treatment of proximal humerus fracture, whereas the rate of malunion is noted between 4 to 20%[34].

NONUNION

Several risk factors have been implicated in the development of nonunion following proximal humerus fracture: metaphyseal comminution, and surgical neck translation between 33% and 100%[16]. Fracture pattern may contribute to the risk of nonunion, with a high propensity for two-part surgical neck fractures compared to other types[3, 20, 23, 39]. Finally, persons who smoke are at 5.5 times higher risk than non-smokers for developing nonunion[22].
Cadet et al[11] have well defined the characterization of the nonunion. The type of nonunion (eg, hypertrophic versus atrophic) should be defined. Radiographically, hypertrophic nonunion are characterized by hypertrophic and sclerotic bone ends with fracture callus, whereas atrophic nonunion appear osteopenic with the absence of callus. In general, hypertrophic nonunion develop when insufficient mechanical stability and/or axial alignment exists and the vascularity and biologic environment for fracture healing is preserved. With atrophic nonunion, vascularity and the biologic environment are often compromised, which causes an inadequate fracture healing response. Radiographs also should be evaluated for evidence of osteonecrosis of the humeral head, pathologic fracture, and extent of bone loss. CT-scan is a useful modality if the diagnosis of nonunion is unclear. Nonunion in long bone fractures is typically diagnosed 6 to 9 months follow following injury[20].
Surgical management is recommended at approximately 6 months following injury if an impending nonunion is suspected, given patient- and fracture-related risk factors (eg, preexisting osteopenia or significant fracture displacement with disruption of the soft-tissue envelope). By intervening at this time point, such action may help to prevent disabling glenohumeral dysfunction that is associated with chronic proximal humerus nonunion[11].
Nonsurgical management for symptomatic proximal humerus nonunion is typically reserved for patients with medical comorbidities that place them at an unacceptable risk for surgical management and for patients who may be at risk for noncompliance with postoperative rehabilitation and precautions. Patients with minimal pain and mild functional losses may be appropriate candidates for nonsurgical management[4].

For surgical neck nonunion, osteosynthesis using locking plate fixation techniques is a therapeutic option in the presence of good bone quality and a viable humeral head in the absence of significant medial calcar comminution or osteopenia that may compromise adequate fixation. The adjunction of bone graft is mandatory to obtain a satisfactory union rate[38] (Figure 1). ORIF with osteosynthesis and bone graft has yielded good results. (Table 1) Historically, results were less favorable following intramedullary nailing to manage proximal humerus nonunion.

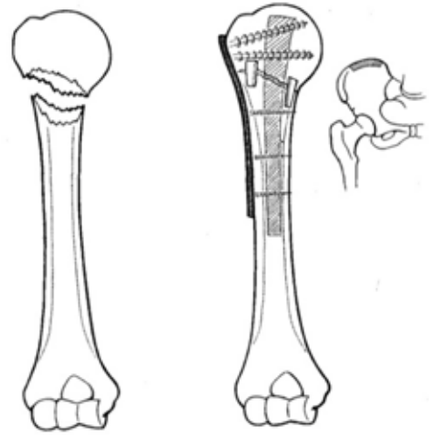


Figure 1
ORIF of proximal humerus nonunion with intercalated corticocancellous autogenous bone graft (D'aprés: Walch G, Badet R, Nové-Josserand L, Levigne C. Nonunions of the surgical neck of the humerus: surgical treatment with an intramedullary bone peg, internal fixation, and cancellous bone grafting. J Shoulder Elbow Surg. 1996 May-Jun;5(3):161-8.)

	Patients	Technique	Graft	Union rate
Healy [23]	13	ORIF	Bone autograft	12/13
Ring [33]	25	ORIF (blade plate)	Bone autograft	23/25
Allende [1]	7	ORIF (blade plate)		7/7
Tauber [37]	55	ORIF (blate plate-45 or humerus-block-10)	No	51/55
Walch [38]	20	ORIF	Corticocancellous autogenous bone graft (iliac crest /anterior tibial crest/midle third fibula)	19/20
Yamane [39]	13	Nail	Bone autograft	13/13
Nayac [30]	10	Open reduction and internal fixation with tension band wiring and Rush rods		8/10

Table 1
Results in literature of ORIF for proximal humerus nonunion

Isolated greater and lesser tuberosity nonunion are less common than surgical neck nonunion. The bone quality of the tuberosity fragment and rotator cuff function are critical components in determining the most appropriate surgical option. In patients with large tuberosity fragments and a viable rotator cuff, osteosynthesis may be achieved with lag screw compression and/or buttress plating with autogenous bone graft. Tension band techniques, transosseous suture fixation, or current suture anchor configurations used in modern rotator cuff repair techniques that provide compression across the fracture site with autogenous bone grafting augmentation can be used for comminuted tuberosity fragments, only if rotator cuff function is determined to be intact clinically. A deltoid-splitting or deltopectoral approach can be used for greater tuberosity osteosynthesis. A deltopectoral approach is suggested for lesser tuberosity nonunion. Arthroscopic techniques have also been described for managing greater tuberosity nonunion[21].
The decision to perform unconstrained arthroplasty (ie, hemiarthroplasty, total shoulder arthroplasty, reverse shoulder arthroplasty) to manage proximal humerus fractures nonunion depends in part on the degree of osteopenia present, the viability of the humeral head and, most important, tuberosity integrity and position as well as rotator cuff functional status. Total shoulder replacement is considered in the setting of concomitant glenohumeral osteoarthrosis with a functional rotator cuff. Reverse total shoulder arthroplasty is a viable option in the setting of proximal humerus nonunion with humeral head collapse and/or a clinically dysfunctional rotator cuff, radiologic rotator cuff atrophy (Goutallier stage 2 or greater) [3, 11, 19, 26].

MALUNION

Malunion may result from a superiorly displaced or externally rotated greater tuberosity, medialization of the lesser tuberosity, varus or valgus neck-shaft angle, or a combination of these factors. These anatomic disturbances can lead to impingement of surrounding structures during shoulder motion and may alter rotator cuff tension. It can also induce joint incongruity which compromise gleno-humeral range of motion[18]. (Figure 2)

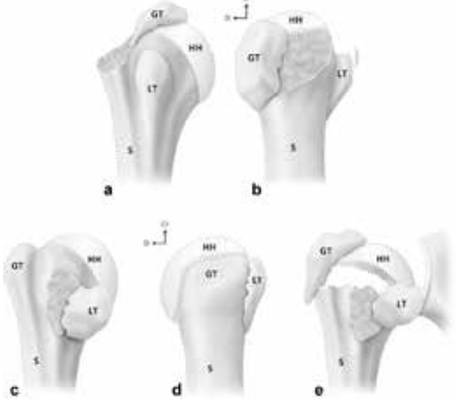


Figure 2
Malunion of the tuberosities (From: Duparc F. Malunion of the proximal humerus. OTSR 2013:99s:S1-S11.)

In two-part, sub-tuberosity, surgical neck fractures, the epiphysis is tilted into varus or valgus, in ventral or dorsal inclination, and the shaft is pulled inwards, forwards and into medial rotation by the pectoralis major, teres major and latissimus dorsi muscles[18].
In three-part, sub-tuberosity, surgical neck fractures where the fracture line extends to the greater tuberosity, the epiphyseal fragment is rotated backwards by the subscapularis muscle and the shaft is pulled inwards and forwards. In three-part fractures involving the lesser tuberosity, external rotation of the proximal humeral epiphysis sends the head forwards. In both cases, the proximal humerus does not have the correct rotation[18].

In four-part, intra-articular, head and tuberosity fractures, both tuberosities are avulsed and the corresponding portions of the rotator cuff may retract. The structural relationships in the glenohumeral joint are disrupted and the joint is no longer congruent: if the head has a valgus deformity in the frontal plane, the glenohumeral angle will be greater; if the head tilts into valgus, the joint space will be narrowed. Any rotation of the humeral head in the axial plane will also alter the glenohumeral joint congruity[18].

Radiographically, malunions are categorized according to their anatomic disruption.

According to the classification of proximal humeral malunions proposed by Beredjiklian et al[6], type I malunion includes malposition of the greater or lesser tuberosity, type II is distinguished by articular incongruity, and type III involves articular surface malalignment. Malposition of the tuberosities is defined as displacement 1 cm from the anatomic position. The greater tuberosity displaces posteriorly and/or superiorly whereas the lesser tuberosity displaces medially. Joint incongruity results from intra-articular fracture extension, posttraumatic osteoarthritis, or osteonecrosis with collapse. Articular malalignment is defined as 45° of deformity with respect to the humeral shaft in the coronal, sagittal, or axial planes and would manifest as alteration in version or in varus/valgus position.

Boileau et al[7] described another classification system that included the sequelae of displaced proximal humerus fractures and the implications for management. Category 1 includes intracapsular injuries and the sequelae of impacted fractures. Type I is characterized by humeral head necrosis or impaction, and type II includes chronic dislocations or fracture-dislocations. Category 2 includes the sequelae of extracapsular fractures. Type III is characterized by nonunion of the surgical neck, and type IV is characterized by severe malunion of the tuberosity. (Figure 3)

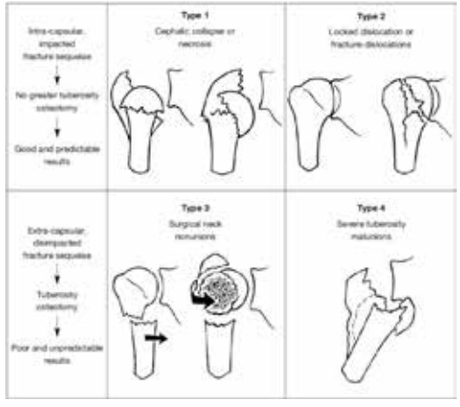


Figure 3
Classification of proximal humerus fracture sequelae (From: Boileau P, Trojani C,Walch G, Krishnan SG, Romeo A, Sinnerton R (2001) Shoulder arthroplasty for the treatment of the sequelae of fractures of the proximal humerus. J Should Elbow Surg 10:299–308.)

Proximal humeral malunion may be well tolerated, depending on the patient's functional requirements. A patient with malunion of the greater tuberosity may exhibit perceived weakness caused by a shortened functional offset of the posterosuperior rotator cuff. Malunion of the lesser tuberosity may result in weakness of internal rotation[13, 15, 16].

In low-demand patients, nonsurgical management of proximal humerus malunion has been found to provide acceptable results[14, 22, 24, 40]. Malunions can often be treated nonsurgically in patients with low activity levels, tolerable pain, significant comorbidities that preclude surgical intervention, and in those who are unable to comply with rehabilitation and/or who are willing to accept some loss of shoulder function[40].

In a systematic review of 12 studies, Lyengar et al[24] found that nonsurgical management of one- and two-part proximal humerus fractures resulted in excellent healing and fair overall Constant scores, with few complications. Three- and four-part fractures also demonstrated predictable evidence of healing on radiography, although final ROM and Constant scores were lower and there were more complications than with nonsurgical management of one- and two-part fractures.

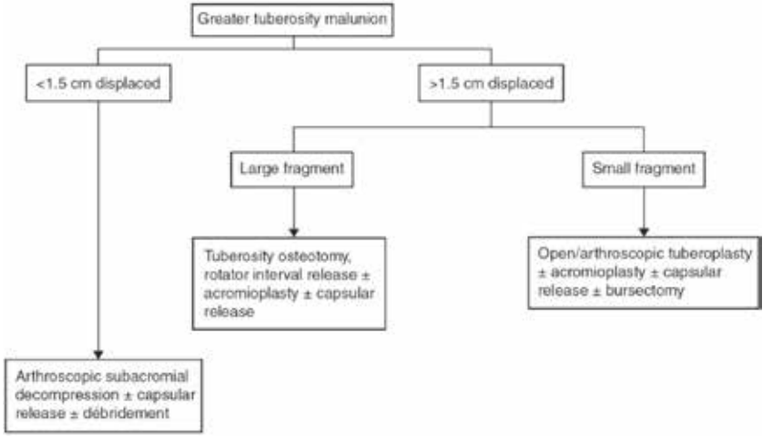
Court-Brown et al[13] retrospectively reviewed 125 patients with impacted valgus fractures managed nonsurgically.

Despite functional losses, 80.6% of patients had good or excellent outcomes and felt that their capabilities were approximately 90% of normal. In a similar review of 99 impacted varus fractures treated nonsurgically, 79% had good or excellent results at 1 year[15].

For patients with persistent dysfunction or pain, however, surgical intervention may improve quality of life. The technique used to address malunion is largely determined by the existing deformity. Surgical options are divided broadly into two categories: humeral head–preserving or humeral head–sacrificing techniques[6]. Osteotomies, soft-tissue releases, and removal of bony protuberances are the main head-preserving procedures. Head-sacrificing techniques are applied in the setting of glenohumeral joint incongruity or degeneration and the development or high likelihood of osteonecrosis. These techniques include hemiarthroplasty, conventional total shoulder arthroplasty, or reverse shoulder arthroplasty (RSA). The challenge is in determining whether the patient's symptoms are the result of bony deformity, soft-tissue dysfunction, or both; failure to address all contributing factors will lead to inferior outcomes[6].

Malunion of the greater tuberosity can result in impingement as well as weakness in forward elevation and external rotation caused by the loss of normal cuff tension. For patients with 1.5 mm of superior migration, acromioplasty may provide enough clearance to address the impingement[6]. Malunions with displacement > 1.5 mm may be addressed with tuberoplasty for smaller fracture fragments. Tuberoplasty involves elevation of the supraspinatus and infraspinatus off the greater tuberosity followed by resection of the bony prominence. The rotator cuff is then reattached to the remaining tuberosity, and an acromioplasty may be performed to increase the acromiohumeral distance. (Figure 4)

Figure 4



Guidelines for greater tuberosity malunion (From: Siegel JA, Dines DM. Techniques in managing proximal humeral malunions. J Shoulder Elbow Surg 2003;12[1]:69-78.)

Malunions of the lesser tuberosity tend to displace medially, resulting in restricted internal rotation. When the articular surface is congruent, an osteotomy can reorient the proximal humerus at the surgical neck while repositioning the tuberosities closer to the normal anatomic position. This requires a lateral closing wedge osteotomy followed by rigid internal fixation. A coracoidoplasty can reduce the anterior sub-coracoid impingement due to a tolerable lesser tuberosity malunion. Injury to the long head of the biceps tendon as it passes through the capsule or in the intertubercular groove can justify a tenotomy tenodesis.

Arthroscopic treatment is indicated to resect any bone fragment(s) that have healed in the wrong position. Resection of the tuberosity fragment and acromioplasty are usually effective in treating subacromial impingement secondary to greater tuberosity malunion, following conservative treatment, internal fixation or arthroplasty. The tuberoplasty can be used to correct the mechanical consequences of tuberosity malunion [12, 25, 28]. Resection of posterior and anterior heterotopic ossifications and release of capsule, labrum, bursa or ligament adhesions can free up the internal or external rotators and restore the subacromial and subdeltoid gliding planes. Symptoms of long head of biceps tendinopathy, because of anatomical alterations in the intertubercular groove, are an indication for tenotomy-tenodesis.

If tuberosity osteotomy is necessary, it must be approached the same way as treating an avulsed rotator cuff tendon attachment. The preparation of the avulsed fragment, the release of the involved tendon for easy mobilization and the hollowing out of a bone recess at the attachment site are all technically demanding steps[18]. Beredjiklian et al[6] reported good results with tuberosity osteotomy and concomitant soft tissue procedures performed to manage isolated malunion of the greater tuberosity with .15 mm of displacement. Osteotomy is reserved for large tuberosity fragments that restrict forward elevation and abduction.

Surgical management of varus malunion of the neck of the humerus with a valgus osteotomy and internal fixation has yielded successful results5. [31, 32, 35, 36] (Figure 5)

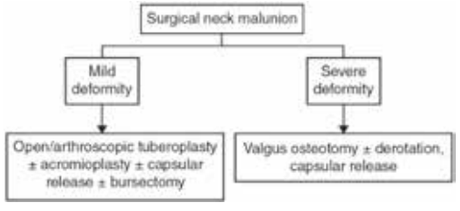


Figure 5
Guidelines for treatment for surgical neck malunion (From: Siegel JA, Dines DM. Techniques in managing proximal humeral malunions. J Shoulder Elbow Surg 2003;12[1]:69-78.)

Sub-tuberosity malunion: varus malunion of the proximal humerus[5]. An osteotomy to correct the deformation and deviation of the proximal humerus must be kept extra-articular to stay away from the epiphyseal vascularization. Analysis of the malunion will lead to a correction in the coronal plan, with a closing wedge valgus osteotomy at the surgical neck corresponding to the amount of correction wanted, but will also correct the anterior or posterior tilt in the sagittal plane and any rotational problems in the axial plane. (Figure 6)

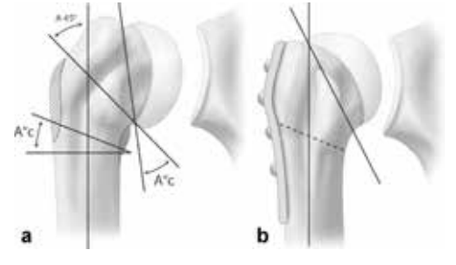


Figure 6
Osteotomy correction of subtuberosity malunion (From: Duparc F. Malunion of the proximal humerus. OTSR 2013:99s:S1-S11.)

In the setting of malunion of the proximal humerus, shoulder arthroplasty remains a technically challenging procedure, even for the most experienced surgeon[2, 7-10, 27]. The anatomy of the proximal humerus can be distorted by prior trauma or surgery, leading to chronic changes in the soft tissues and bone[6, 17, 27]. The use of a modular shoulder system and short-stem or stemless humeral implants can be useful[9, 17]. Factors associated with worse outcomes following arthroplasty include the need for greater tuberosity osteotomy, advanced age, rotator cuff dysfunction, poor participation with rehabilitation, and prior surgical intervention[2, 9, 17, 27]. In many cases of malunion, the greater tuberosity sits in a posterior and/or superior position. Boileau et al[9, 29] reported "predictably good" clinical results following unconstrained arthroplasty for type 1 intracapsular fracture sequelae that did not require tuberosity osteotomy.(Figure 7)

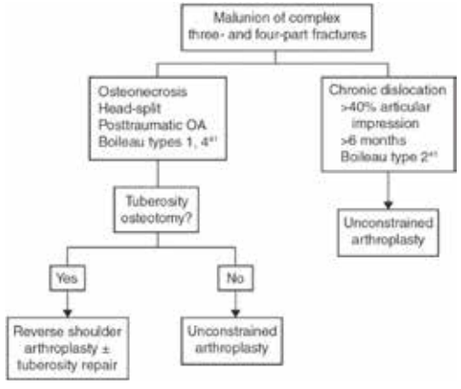


Figure 7
Guidelines for treatment of malunion of complex three- and four-part fractures (From: Siegel JA, Dines DM. Techniques in managing proximal humeral malunions. J Shoulder Elbow Surg 2003;12[1]:69-78.)

Patients with type 4 sequelae had poor results following unconstrained arthroplasty with concomitant greater tuberosity osteotomy. Most authors have reported inferior outcomes following unconstrained arthroplasty with tuberosity osteotomy[8, 27]. When osteotomy can be avoided, the humeral stem is placed in a nonanatomic position to accommodate the malpositioned tuberosities [9, 26, 27]. Boileau et al recommended the use of the RSA to manage type 4 malunions when an osteotomy of the greater tuberosity was required[9].

Reversed total shoulder implant can be justified if the rotator cuff is not functional or cannot be repaired (after nailing) or the tuberosities cannot be repaired. If the implantation can be done without tuberosity osteotomy, the procedure will be easier. If a tuberosity osteotomy is required for the implantation, repositioning the tuberosity seems to be simpler since the tendons and tuberosities have been resected. The rotation cuff does not need to be spared in such cases. Release

of contracted soft tissues will also contribute to improvement in the joint range of motion. Keeping all or part of the subscapularis can preserve some degree of useful internal rotation. Similarly, sparing the teres minor muscle could help to provide a bit of external rotation. A positive hornblower sign before the arthroplasty is predictive of a poor outcome, especially in elderly patients[9].

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10/ HOW TO MANAGE THE FAILED OSTEOSYNTHESIS

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The proximal humeral fracture (PHF) is a common and difficult to treat fracture entity. Delineate the exact pattern of the fracture even with sophisticated imaging ,this will influence the selection of fixation techniques .Still yet, there is no consensus on whether surgical or non-surgical treatment should be recommended for dislocated PHFs. Even for the selected implant devices there is no consensus amount surgeons.
Furthermore, no approved treatment guidelines exists for the treatment of failed osteosynthesis, independent of the treatment modality . The proximal humerus fracture represent the fourth-most common fracture among geriatric patients and still yet characterized by high complication rates of up to 49%,and revision rates up to 1/3 .
Bone quality influences the appropriateness of any intervention. Most important factors for the stability of locking plate are bone mineral density and the medial support.
Indipendent of the chosen implant loss of reduction which leads to failure of the osteoynthesis still yet represent a major complication and guidelines how to procede are still lacking.

Locked plating is known to be a popular treatment option for surgical treatment of PHFs. recent studies, however, show high failures rates after fixation of proximal humerus fractures with a range from 8.6% to. 22.0%. Loss of reduction and screw cut-out are the most common reasons for revision surgery. Risk factor for subsequent re-operation independent of the treatment modality can be osteoporosis ,involvement of the medial calcar and multifragmentary fracture pattern.
To understand the source of failures is mandatory for revision surgery where we have to distinguish between" joint preserving" surgical procedures or" shoulder replacement" strategies.

JOINT PRESERVING STRATEGIES

Technical failures include inadequate reduction which can result in loss of fixation and secondary mal union. Hardware prominence which subsequently needs early hardware removal may be a source of failure.

Non union

For non unions responsible biomechanical problems are for example inadequate selection of the implant resulting in an inadequate stabilization . For example in this young patient where the subcapital fracture was tried to stabilize with a helix wire resulting in a distraction of the fracture ("jack in the box phenomenon") which lead to a non union, requiring revision surgery .We selected a joint preserving approach and reconstruct the proximal humerus non union with autogenous bone graft ,removed from the ipsilateral iliac crest, and hook plate osteosynthesis.

Figure 1

Figure 2

A further case of irregular selection of an implant device (Total Elastic Nail: TEN) that also leads to a symptomatic non union do to rotational instability.Revision surgery was mandatory .
A similar approach was used . Hook plate fixation and autogenous bone graft from the right iliac crest. (Fig. 2)

Sources for non union can also be poor vascularity (iatrogenic traumatic) or infections, not seldom low grade infections with propionic acne. Therefore we recommend always soft tissue sampling in case of revision surgery.

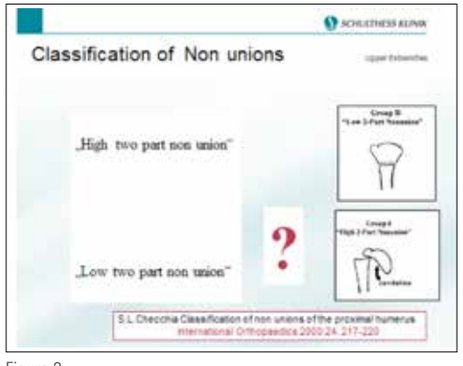

Figure 3

For " Low two part non unions" where head cavitation is present where a stable fixation with an implant device is not feasible consider a shoulder arthroplasty.(Fig.3)

Figure 4

This example shows failure of Reosteoynthesis of a symptomatic pseudarthrosis . (Fig.4) We were not able to prevent "slippage of the head" do to advance head cavitation. In this situation recommendation for shoulder arthroplasty would have been more opportune.

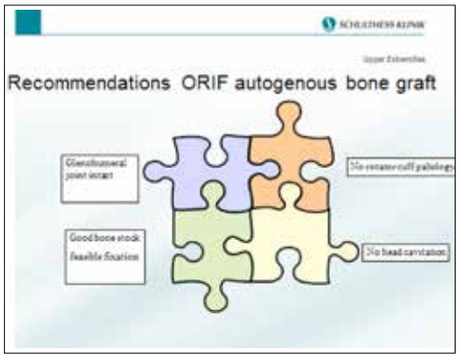

Figure 5

In compliance with the requirements, joint preserving approaches can lead to predictable good results . (Fig.5)

Mal union

Mal union can lead to malposition of the humeral tuberosities, rotational or angular deformity, and/or offset of the head-shaft junction, or articular incongruities.
Proximal humeral mal unions are a complex problem that can challenge even the experienced shoulder surgeon.
Severe mal unions compromise functional results.
Corrective osteotomies may be considered to decrease pain and improve function.

Figure 6

In this patient there was a reasonable suspicion of mal rotation
which could be confirmed by CT scan measurement. Compared with the uninvolved extremity an increased retroversion of 70 degree was depicted. Therefore a Derotation Osteotomy was performed and a full recovery of shoulder function could be achieved one year after revision. (Fig.7)

Figure 7

Angular Deformity resulting after Osteosynthesis in MIPO Technique of a subcapital proximal humerus fracture.(Fig.8a)

Figure 8 a

A "two step" procedure was necessary to restore a free of pain functional full recovery. In a first step an arthroscopic release of soft tissue followed by removal of the plate was done. Postoperatively patient still complained for rotational limitation especially for external and internal rotation. Furthermore a corrective osteotomie was performed to regain a nearly free full function . (Fig 8b)


Figure 8 b

JOINT REPLACEMENT

Prosthetic replacement represents a good surgical option to treat proximal humerus fracture sequelae with or without osteoarthritis . 2001 Boileau et al. (Fig 9) established an updated classification system and treatment guidelines for these complex situations. They described a new surgical classification in order to improve ability and to anticipate the expected final outcome.

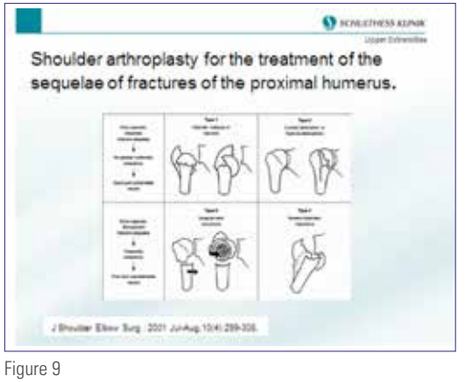

Figure 9

More specifically they found that functional results were acceptable and more predictable in cephalic collaps and necrosis (Typ 1) with slight distorsion of anatomy. Also for locked or fracture dislocation (Typ 2) functional results were acceptable using a non constrained shoulder arthroplasty. Based on the experiences of the authors, results using non constrained shoulder arthroplasty particularly in lesions which represent surgical neck non unions (Typ 3) and in (Typ 4) lesions who are characterized by severe Mal union of the tuberosity, are dissatisfying. Today for Typ 3 in the present of osteoarthritis or a cuff lesions, and for Typ 4 lesions reverse shoulder replacement represents the "treatment of choice". (Fig.10) Despite non union or mal union of the tuberosity in Typ 4 lesion Reversed shoulder arthroplasty gives acceptable results. Beside patient's age the choice of the surgeon should be guided by the type of fracture sequelae according to the classification proposed by the authors.

Figure 10

CONCLUSION

Understanding the etiology and pathoanatomy of failure of Osteosynthesis of proximal humerus fracture, is mandatory for a patient specific approach which includes joint preserving strategies and joint replacement.
We believe that treatment strategies should be individualized and must consider the specific basic pathology. Therefore, there is no "simple single solution" or a universally valid guideline. An individual approach is mandatory to made an individual decision, not at least taking in consideration also expectation of the patient. Surgery should be individually adapted, and even a" watchful waiting strategy" "especially in the young patient is also valuable to consider.

11/ EARLY AND LATE COMPLICATIONS OF HEMIARTHROPLASTY

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INTRODUCTION

The prevalence of proximal humerus fractures (PHF) is continuously rising due to demographic changes. 4-5% of all skeletal fractures involve the proximal humerus and 33% of the patients are older than 60 years pointing in the direction that one of the major risk factors is age.[18, 23, 27, 38, 45] Up to 80% of the patients are female and fractures of the proximal humerus are usually caused by low-energy trauma in the presence of osteoporosis in the elderly population.[12, 49] Among these fractures, especially 3- or 4-part fractures involving the humeral head and tuberosities are difficult to treat.
Historically, the Neer prosthesis was the first arthroplasty for replacement of the humeral head in cases of commintued fractures with fixation of the tuberosities around the hemiarthroplasty. For a long time hemiarthroplasty (HA) has been the gold standard for the treatment of comminuted PHF in the elderly population, which were not suitable for open reduction and internal fixation or conservative therapy.[33] However, in the last decades utilization of HA has become increasingly controversial and reverse shoulder arthroplasty (RSA) for fracture has been gaining more popularity.[1, 24, 34, 46, 48] Nowadays the question rises whether there is still an indication for fracture HA and if it should remain in the armentarium of the shoulder surgeon.[5] Because the surgical procedure is technically challenging, can give unpredictable results, and is rarely performed, many surgeons prefer to choose different options such as conservative treatment with short-term immobilization and early functional exercises, angular stable plate osteosynthesis or intramedullary nailing and reverse shoulder arthroplasty.[7, 9, 23, 24, 27, 34, 36, 51] Numerous studies compared the results and complication rate between HA and RSA for fractures of the proximal humerus. In a systematic review and meta-analysis Gallinet et al. found better clinical outcome for patients treated with RSA independent of tuberosity healing.[16] In most of the studies included, the complication rate after RSA was higher compared to HA. However, the rate of revision surgery was equal and the rate of implant change is higher after HA.[16] Complications specific for HA may be divided into three chronologic categories: intraoperative, early postoperative and late postoperative.[41] The outcome of hemiarthroplasty and possible need for revision surgery is closely related to anatomic tuberosity healing and restoration of rotator cuff function.[29] The functional outcomes reported in the literature have been poor and often not predictable, with a high rate of up to 50% of complications related to the tuberosites.[2-4, 11, 13, 25, 30, 31, 35, 37,40] Complications following HA may be related to surgical errors and/or technological insufficiencies of the prosthesis designs. This article is intended to report about the early and late complications of hemiarthroplasty following fractures of the proximal humerus.

INDICATIONS AND LIMITATIONS FOR HEMIARTHROPLASTY

Primary HA is a treatment option for complex comminuted fractures in patients with a functional rotator cuff, when adequate reduction and fixation of the fracture fragments cannot be achieved or the risk for osteonecrosis is very high. The aim is to restore functional biomechanics of the shoulder and achieve pain relief with a satisfying range of motion. Hemiarthroplasty is usually preferred to total shoulder arthroplasty in acute fracture situations, as relevant cartilage damage of the glenoid is not present.[43] Furthermore, the avoidance of a glenoid component complication such as loosening or eccentric wear and the possibility of secondary conversion to total shoulder arthroplasty might be reasons for applying a hemiarthroplasty.[42] Possible indications are a short (<8mm) metaphyseal head extension, disruption of the medial periosteal hinge, a shell-like head fragment, and non-reconstructable head-split or humeral head impression fractures.[21] Different designs with modularity facilitate the restoration of the relationship between humeral head and the tuberosities by variable adjustment of the humeral height, offset and retroversion.[26, 34] In a retrospective case series of 56 displaced four- or five part PHF that were treated with HA Boileau et al. found that risk factors associated with poor functional results and anatomic failures were patient age above 75 years, patient gender (women), and use of conventional bulky stems, which are not specifically designed for fracture treatment. The authors concluded that in patients older than 75 years and women with displaced comminuted fractures an RSA instead of HA

should be applied.[5] Due to poor bone quality and osteoporosis, union of the tuberosities and healing potential is insufficient in this group of patients limiting the success of HA. Therefore, RSA should be applied when healing of the tuberosities cannot be expected and a functionality of the rotator cuff is questionable.

INTRAOPERATIVE COMPLICATIONS

Intraoperative complications or errors specifically related to HA, are malpositioning of the components, iatrogenic fractures and injuries to the axillary nerve.[43]

In HA cases requiring revision, quite often, a high placement of the stem, a supposedly non-physiological humeral retrotorsion, and an excessive size of the head component can be observed. A few landmarks can be used to avoid malpositioning of the HA. The upper margin of the pectoralis major tendon insertion constitutes a reliable landmark and is helpful in determining the correct position of the prosthesis, the humeral height and retroversion.[47] Also, the bicipital sulcus can help to identify the former physiological retrotorsion of the humeral head.[22] Additionally, the size of the fractured humeral head can be used to help determine the correct size of the humeral head component. Another important intraoperative pitfall is the attachment of the tuberosities. Concerning nonunion or displacement of the tuberosities, Frankle et al. showed that reconstruction of four-part fractures with HA should incorporate a circumferential medial cerclage involving both tuberosities.[15] In biomechanical tests, application of a cerclage decreased interfragmentary motion and strain[15]. Reattachment of the tuberosities with cable wire and additional bone-grafting produced better radiographic results with regards to healing, displacement and absorption leading to superior functional results compared to an isolated suture fixation.[26] Boileau et al. found also that the use of specific fracture stems does reduce the rate of tuberosity complications after surgery and is associated with better anatomic and functional outcomes.[5]

Iatrogenic fractures might especially occur in cases of poor bone quality and stiff soft tissues.

Injuries to the axillary nerve or brachial plexus are rare. In a systematic review by Ferrel et al. the overall rate of injuries to the axillary nerve or the brachial plexus was 0,5%.[14] However, when nerve palsy occurs this can be devastating for the patient and shoulder function.

EARLY COMPLICATIONS

Complications occurring within a few weeks following HA are considered as early complications and often require revision surgery. Other than non-specific complications as postoperative hematomas, acute infection, and stiffness, early postoperative complications include detachment of one or both tuberosities and instability. The infection rate is generally low with 1-2% and comparable with other surgeries for PHF.[24] Similarly also stiffness after HA which is reported in up to 5% of the cases is comparable to the fequencies of stiffness after other surgeries.[16] Early detachment of the greater or lesser tuberosity is reported in up to 23% of the cases.[16] However, most of the studies do not differentiate between early displacement and later noted malunion or absorption of the tuberosities. Instability can especially occur when insufficient concavity compression is exerted on the prosthesis head by the surrounding muscles. This can be either caused by tuberosity displacement, pre-existing cuff defects, or nerve palsy.

LATE COMPLICATIONS

Complications occurring several months after HA are considered as late complications. Most of these complications are related to the tuberosities and the lacking integrity of the rotator cuff. Missing structural integrity of the horizontal and vertical force couple of the shoulder leads to dynamic and static instability of the prothesis and consecutive loss of function. (Figure 1)

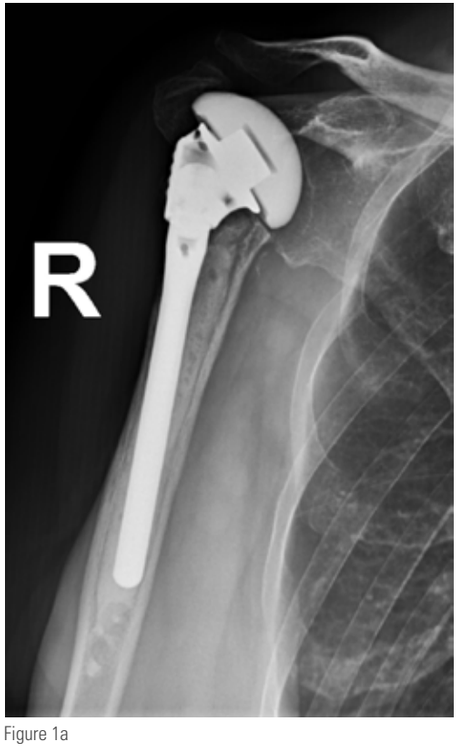

Figure 1a

Figure 1b

Figure 1c

Figure 1
Poor clinical function after hemiarthroplasty for proximal humerus fracture due to tuberosity insufficiency and secondary superior migration of the head.

Complications related to the tuberosities including absorption, malunion, and non-union are reported in up to 50% of the patients treated with HA for PHF and lead to poor clinical outcome and often represent the reason for revision surgery.[2-4, 11, 13, 25, 30, 31, 35, 37, 40] Secondary erosion of the glenoid is reported in up to 35% of the cases following HA and might also be a reason for revision surgery. The risk for loosening and periprosthetic fractures is comparable to arthroplasty for different indications.

REVISION SURGERY FOLLOWING HEMIARTHROPLASTY

Early displacement, malunion, non-union, absorption, or secondary rotator cuff insufficiency often lead to dynamic or static instability of the HA. These patients are usually revised with RSA, which aims to increase stability by being a more constrained design and is not dependent on the integrity of the tuberosities and rotator cuff in order to function. Satisfactory clinical outcomes have been reported in the literature regarding conversion of HA to RSA.[17, 19, 20, 28] Patients can expect an improvement of shoulder function and pain relief after revision surgery.[39] However, in comparison to patients treated for osteoarthritis the patients treated for PHF have a lower subjective outcome and a higher complication rate.[19] Additionally, the removal of the typically well-fixed cemented stem can be difficult and require humeral osteotomies. (Figure 2)

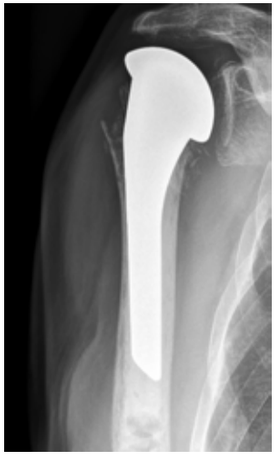

Figure 2a

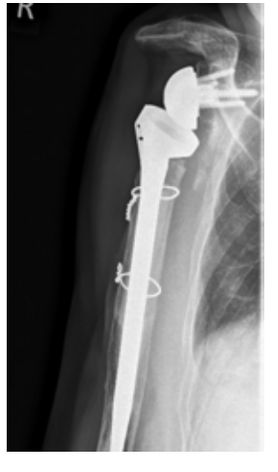

Figure 2b

Figure 2
Hemiarthroplasty for proximal humerus fracture failed due to tuberosity insufficiency and secondary superior migration of the head. Conversion to reverse shoulder arthroplasty with complete stem removal by means of a humeral osteotomy and insertion of a long stem

Convertible humeral components bear the potential advantage of preservation of humeral bone stock, shorter operating time at revision and lower complication rates.[8, 50] (Figure 3)

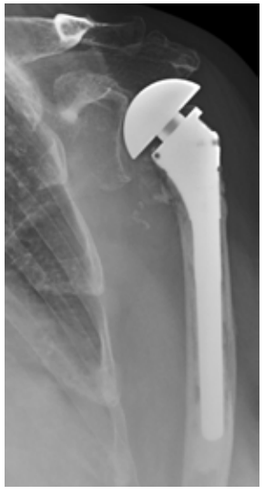

Figure 3a

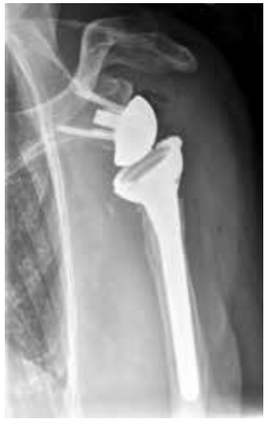

Figure 3b

Figure 3
Hemiarthroplasty for proximal humerus fracture failed due to tuberosity insufficiency and secondary superior migration of the head. Conversion to reverse shoulder arthroplasty without stem removal by means of a modular and convertible prosthesis design

Correct positioning of the prothesis especially with regards to height and retroversion of the prothesis can be challenging when metaphyseal bone is missing or the tuberosities are necrotic or displaced.[6, 10] Additionally, the lack of tuberosities increases the risk for instability and often results in a very limited internal and external rotation. In cases with severely deficient proximal humeral bone stock allograft augmentation might be an option to increase stability and function.[6]

DISCUSSION

HA for treatment of PHF might be an option in the case of severe comminution and clearly compromised vacsularity of the humeral head. Evolutions in implant design, tuberosity fixation techniques and the development of fracture-specific humeral stems represent attempts to rectify some of the major problems of HA for fractures. However, with surgeons rarely performing HA for PHF and the procedure being technically difficult, its use has become increasingly controversial.[24, 34] A systematic review by Kontakis et al. concluded that there is no strong evidence to support the effectiveness of HA for the treatment of PHF due to high rate of complications related to the tuberosities. As a result, the treatment decision process in cases of PHF has changed. In recent years RSA for fracture has become increasingly widespread and the indications have expanded. Especially in the elderly population having a high risk for fracture sequelae with non-union, malunion and necrosis of the tuberosities RSA might be indicated. This technique is less dependent on a functional rotator cuff and tuberosity healing than HA. Numerous studies and systematic reviews exist comparing the results of HA and RSA for the treatment of PHF. Most of the studies report comparable outcomes in shoulder function. However, in most studies the complication rate for RSA is higher compared to HA, while the revision rate is lower. Namdari et al. reported an overall complication rate of 19.4% following RSA compared to 5.6% following HSA. The rate of reoperation was 4.5% after RSA and 9.1 after HA and the need for revision with implant change was 1.5% (RSA) vs. 6.4%.[32] Revision surgery following hemiarthroplasty can lead to satisfactory outcome but remains a challenging and often unpredictable surgery due to potential bone loss. According to Sebastia-Forcada et al. the main reason for RSA being more predictable is, that outcomes are less dependent upon healing of the tuberosities.[44] Especially the reliability and reproducibility of the outcomes after RSA in shoulder function are important elements to consider when faced with trauma in older adults.

CONCLUSION

The role of HA for the treatment of comminuted fractures of the proximal humerus with compromised vascularity has become increasingly controversial. The clinical results and possible need for revision surgery are highly dependent on anatomic tuberosity healing and thus restoration of rotator cuff function. Since complications with the tuberosities can be observed quite frequently it is important to anatomically reconstruct the bony and soft tissue anatomy with high fixation strength and to consider using modular convertible systems when performing HA for PHF.

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12/ WHAT TO DO WHEN REVERSE FOR FRACTURE FAILS?

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Although controversy remains regarding the optimal management of various patterns of proximal humeral fractures, over the last decade reverse shoulder arthroplasty has emerged as a commonly considered treatment option for complex fractures, especially in older patients. (1-3) Most surgeons agree that fixation of the fractured tuberosities should be performed at the time of reverse for fracture, and the majority of reverse arthroplasties performed for fracture use cement fixation for the humeral component. (4-7)

Reverse arthroplasty has been reported to provide a good outcome in a large proportion of patients with proximal humerus fractures; however, complications do occur.(8, 9) The question then becomes what to do when reverse for fracture fails, and to some extent treatment alternatives depend on the mechanism of failure. There is limited information in the literature regarding revision of a failed reverse to another reverse, (10-12) and ever more so regarding specifically what to do for the failed reverse for fracture.

FAILURE MECHANISMS

Any of the complications that can occur after reverse for any indication can obviously occur after reverse for fracture. The most common complications of reverse for fracture include failure of the tuberosities to heal properly, humeral component loosening, dislocation, nerve injury, stress fractures of the acromion or the spine of the scapula, notching with polyethylene wear, and periprosthetic joint infection. Some of these complications occur in combination. For example, tuberosity resorption will not only lead to cuff dysfunction, but may also facilitate dislocation or humeral component loosening. Similarly, advanced scapular notching with substantial polyethylene wear and osteolysis may lead to component loosening.

EVALUATION

When evaluating the patient with a failed reverse arthroplasty for fracture, understanding patient's expectations is paramount. Some patients with nonunion or resorption of the greater tuberosity may lack active external rotation but may complain of no pain and reasonable active elevation. On the other hand, periprosthetic joint infection or component loosening may present with incapacitating pain that requires revision surgery.

MANAGEMENT

Provided pain or dysfunction are substantial enough to warrant additional surgery, the treatment strategy will differ according to the failure mechanism. Review of all possible failure mechanisms of reverse for fracture is beyond the scope of this paper. We will discuss next management of the most common complications.

Periprosthetic Joint Infection

Two-stage reimplantation is considered by many the standard of care for periprosthetic joint infection after shoulder arthroplasty, including reverse prostheses.(13) (Figure 1)

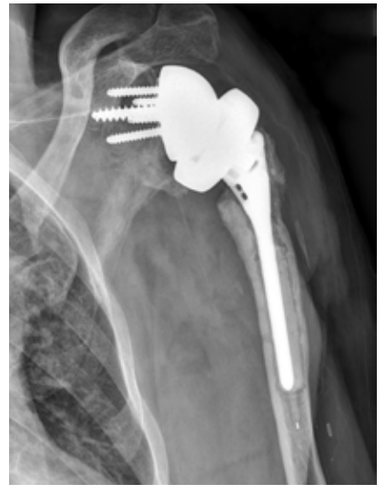

Figure 1
Anteroposterior radiograph demonstrate humeral loosening at the cement-bone interface in a patient with a deep infection complicating a shoulder arthroplasty for fracture

Ideally, all foreign material -including components, nonabsorbable sutures, bone cement, and cement restrictors- should be removed at the time of resection arthroplasty. A cement spacer is typically placed at the time of resection. Some low-demand patients experience resolution of their pain and other infectious symptoms after their resection and placement of cement spacer and choose not to undergo further surgery. Patients interested in better restoration of function oftentimes elect to proceed with the second stage reimplantation. One stage reimplantation can also be considered selectively.(14)

Tuberosity failure

Failure of the greater or the lesser tuberosity to heal in a satisfactory position is the main mode of failure of hemiarthroplasty for fracture.(15-17) One of both tuberosities may remain nonunited, heal in a malunited position, or simply fragment and resorb. Although reverse arthroplasty has been reported by some to be associated with better rates of tuberosity healing, (4, 6, 7, 18), tuberosity failure can also occur after reverse for fracture. (Figure 2)

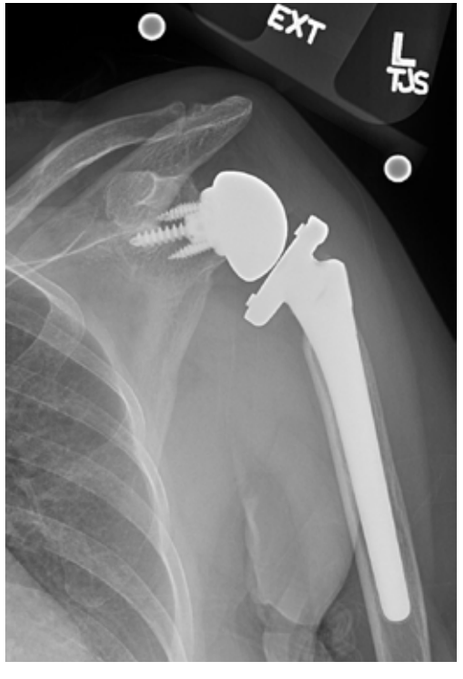

Figure 2
Anteroposterior radiograph shows complete resorption of the greater tuberosity after reverse for fracture

As mentioned previously, some patients with failure of the greater tuberosity still experience good pain relief and reasonable motion in elevation. However, other patients with greater tuberosity failure may have very poor active external rotation, to the point of considering further surgery. The question then becomes how to best restore active external rotation.

Occasionally, if computed tomography confirms the presence of a reasonable tuberosity fragment, a superior approach may be considered to mobilize the posterosuperior rotator cuff and perform a revision internal fixation of the greater tuberosity to the prosthesis with bone grafting. When no greater tuberosity is identified, the only solution is to consider a tendon transfer. Transfer of the latissimus dorsi is appealing provided the tendon of the latissimus dorsi had not been compromised in prior procedures. The published experience using a latissimus dorsi tendon transfer in patients with a prior reverse shoulder arthroplasty is limited to one study with mixed results. (19) If the latissimus dorsi is compromised, consideration may be given to transferring the lower trapezius; the results published to date do not include patients with a prior reverse arthroplasty. (20) A potential challenge with transfer of the lower trapezius is the need to extend the length of the tendon with an allograft, with the potential for compromised healing in the absence of a greater tuberosity.

When proximal humerus bone loss is substantial, transferred tendons cannot be reinserted unless the humeral side is revised to an allograft-prosthetic composite with cuff allograft (21, 22) or a segmental metal prosthesis with soft-tissue attachment sites. At this point, the healing rates of transferred tendons to metal prosthesis or allograft cuff remains largely unknown.

Component loosening

Overall, humeral loosening is an uncommon complication after reverse shoulder arthroplasty. When humeral loosening occurs after reverse for fracture, reasons may include deep infection, lack of proximal humeral support for rotational stability of the component if the tuberosities fail to heal, late loss of proximal humerus bone support secondary to osteolysis in patients with polyethylene wear or notching, and use of uncemented components with suboptimal primary stability. Depending on the extent of bone loss at the time of revision surgery as well as the quality of the remaining bone, revision of the humeral component may be performed with a cemented standard length or long length stem, a dedicated cementless revision component, an allograft prosthetic composite, or a segmental modular replacement prosthesis.

Glenoid loosening is very uncommon after reverse for fracture. These patients typically present with a completely intact glenoid, with no deformity and good bone stock. The main potential issue when performing the primary arthroplasty for fracture is not to remember that these individuals will not have subchondral sclerosis, and as such it is very easy to unintentionally over-ream. If glenoid loosening occurs, infection should be suspected. Late glenoid loosening can also occur secondary to notching and polyethylene wear. Revision requires use of techniques to achieve adequate primary stability and manage bone loss.

Dislocation

The overall rate of prosthetic dislocation after primary reverse shoulder arthroplasty has definitely decreased for the majority of the indications, especially cuff tear arthropathy and primary osteoarthritis. Dislocation of reverse after fracture is uncommon unless the tuberosities fail to heal. (Figure 3)

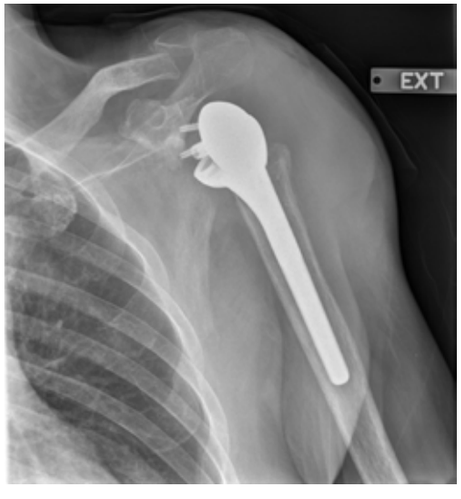

Figure 3
Dislocated reverse arthroplasty for fracture after implantation of a medialized design and resorption of the greater tuberosity

In fact, patients sometimes will develop stiffness or even heterotopic bone formation. When dislocation occurs, it is important to analyze each shoulder individually in order to identify possible contributing factors.(23) These may include relative shortening of the humerus if the component was inserted too low, loss of lateral offset of the shoulder, tuberosity resorption, inferior impingement, and an associated axillary nerve injury. Closed reduction may be successful if the dislocation occurs early on(24), but not uncommonly revision surgery is required to address one or more of the factors mentioned above.(25)
Illustrations

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13/ HOW TO PREVENT AN INFECTION IN RTSA?

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INTRODUCTION

Reverse Total Shoulder Arthroplasty (RTSA) infection is a rising problem which progresses with the incidence of its implantation around the world. If the treatment of a confirmed infection grossly follows the rules that surgeons have learned from hip surgery (deep enarthrosis replacement with good muscle coverage), the prevention of RTSA infection needs a specific reflexion adapted to shoulder germs specifically Cutibacterium acnes (CA)(2) and to new indications such as reoperation after cuff repair particularly in male cases. This presentation will be focused on those specific subjects excluding general considerations concerning total joint replacement (air filtration, helmet systems, MRSA screening, draping...).

WHAT IS THE PROBLEM?

Even if RTSA infection remains underdiagnosed because of low aggressiveness of shoulder germs (CA and Staphylococcus epidermidis) and also because of limited number of national registers able to evaluate the RTSA revision rates specifically due to infection, some clues have cautioned shoulder surgeons. Last ten years have been marked by a dramatic increase of RTSA implantations mainly based on the widening of their indications in traumatic and revision cases, but also in younger active population for early dysplasic degenerative arthritis or cuff arthropathies after failed cuff repairs. A «CA terrible triad» has appeared through the association male gender + aged less than 65 years + previous surgery of the implanted shoulder. This at-risk triad had first been identified retrospectively by Morris et al (12) with a 5% rate of RTSA infection much higher than for anatomical prosthesis, and CA had yet been recognized as the «most prevalent pathogen» (fig 1).

Figure 1
prevalence of pathogens in a 2009 multicenter Venus Group study (infected TSA)
courtesy P Valenti, J Kany, D Katz

Lehtimäki et al (9) confirmed with a prospective register study that infection is the main cause of TSA revision, and that male sex (2.5 fold higher risk) was associated with a significantly higher risk of revision specifically when associated with RTSA (fig 2).

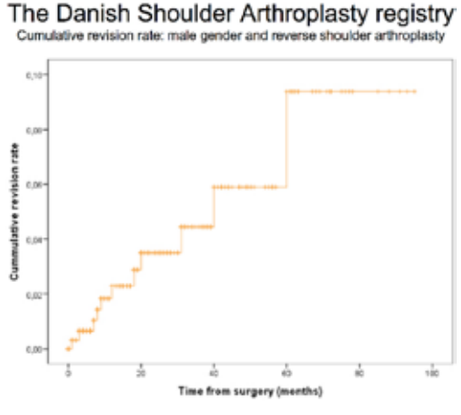

Figure 2
experience of the Danish register shoulder
Courtesy J Rasmussen (EBJIS 2017, Nantes)

Werthel et al (19), reported that previous non arthroplasty surgery doubles the risk of infection with, conversely, a significant lower risk associated with older age and female gender. This risk seems to be the same in case of previous arthroscopic procedures (5). In those cases, the operative

wound must be considered as a battle field contaminated by CA (a deeper pathogen) and S. epidermidis (a surface pathogen) in 10 to 40% of the cases (6, 11) at previous procedure during which those germs are brought from the skin to the implantation site. The risk of progression from tolerated contamination to infection may be aggravated by factors such as post-operative hematoma, poor close muscular coverage of the prosthesis or dead spaces at the back-side of the glenosphere (fig 3) or around a non-cemented porous stem (7), all factors facilitating germs proliferation and biofilm production (2).

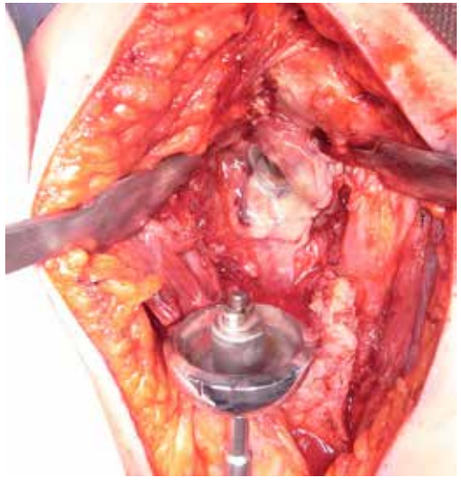

Figure 3
CA RTSA infection with the glenosphere backside «cloaca»

The questions are now much more how to prevent infection than how to treat it: 1) is the prevention adequate in case of first RTSA? 2) Is there a specific prevention in case of a «CA terrible trial»?

ANTIBIOPROPHYLAXY

This question remains partially unsolved. During primary surgery, Phadnis et al (14) reported that skin preparation and cefazolin preoperative injection do not completely eliminate CA from operative dermis. Matsen et al (10) had the same conclusions from deep cultures after preoperative intravenous ceftriaxone and vancomycine considered to be more effective on CA than Cefazolin alone. Nevertheless, recommendations are still to use this latter antibiotic (2g one hour before incision) in most of the cases, except in case of penicillin allergy or known risk of methicillin resistant staphyloccocus aureus contamination (1). In case of previous non arthroplasty, or non-infected shoulder surgery, the question is now whether the surgeon has to adapt antibioprophylaxy to a suspected specific pre-operative site contamination with commensal shoulder germs. The need for pre and per-operative in situ bacteriological sampling associated with immediate post-operative therapeutic antibiotherapy is still an inconclusive debate between surgeons and infectiologists (18). All those authors have demonstrated that general antibioprophylaxy is probably not the major tool of TRSA prevention of CA infection and that conventional skin preparation remains insufficient to reduce CA infection risk and could become the major target of RTSA infection prevention during all shoulder surgeries whatever they are, arthroscopic or open.

SKIN PREPARATION AND PRE-INCISION DECONTAMINATION: PREVENT RTSA COLONIZATION

It's now demonstrated that CA is implicated in most of the primary contamination and secondary infection of RTSA and that it needs specific prevention apart from regular joint replacement rules. It has also been demonstrated that CA is a normal resident of the subcutaneous layers (fig 4) but not of the deep anatomic structures (15) where it is brought by the surgeon's instruments during previous non arthroplasty surgery, RTSA implantation, or both!

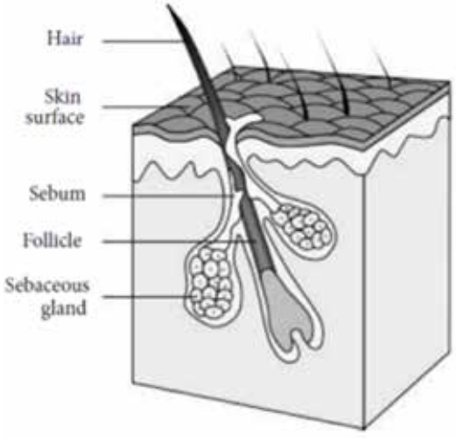

Figure 4
One million germs could be present in each follicle which reaches the density of 80-100/cm2 in subcutaneous layers of men shoulders

Hudek et al (6) taught us that it is preferable to go around the topographic «at-risk area» of the shoulder by using anterior rather than superior approach (fig 5).

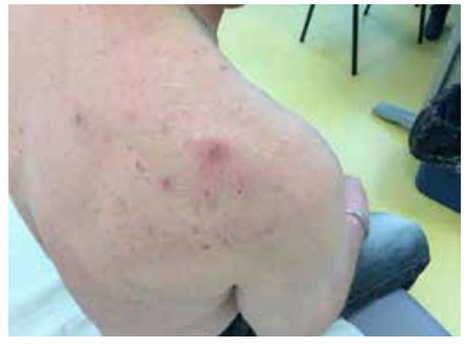

Figure 5
Topographic evidence of CA residency around young men shoulder

The actual solution is probably to eradicate, as much as possible, the deep skin burden of CA by specific skin preparation. Based on Saltzman et al study (17), Clark et al recommend Chloraprep or a Chlorexidine based solution for skin preparation, with completed drying before draping (1). Recently Heckman et al (4) outlined the persistence of CA in the surgical site whatever was skin preparation, whereas Nakase et al (13) demonstrated the low susceptibility of CA to Chlorexidine. Some authors, following dermatologist experiences in acne treatment, advocate the use of preoperative benzoyl peroxide (BPO) applications the days before surgery with a demonstrated decrease of CA contamination superficially and in the deep layers, respectively with BPO alone for Sabetta et al (16), Kolakowsky et al (8), and BPO plus clindamycin for Dizay et al (3). Those studies need to be consolidated by further prospective randomized studies to demonstrate that adjunctive preoperative skin preparation with BPO could be the pertinent tool, particularly in case of at-risk «CA terrible triad».

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PART 2

Anatomic shoulder arthroplasty: New trends and controversies

14/ 9-13 YEAR RESULTS OF STEMLESS HUMERAL HEAD REPLACEMENT. A PROSPECTIVE STUDY

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AIM

Since the introduction in 2005, stemless humeral head replacement have become established. Longterm results are not available until now.
The aim of the study was the evaluation of long-term results of shoulder arthroplasty using a stemless humeral head component.

MATERIAL AND METHODS

Since 2005 we documented stemless humeral head replacement using a single type of implant (EclipseTM, Arthrex Inc.) prospectively. The design objective of Eclipse (Fig.1a) was to develop a stemless humeral head replacement enabling the anatomic reconstruction of the center of rotation of the humeral head independent from the shaft axis, especially in posttraumatic conditions.

Figure 1a
EclipseTM (Arthrex Inc.)

Contraindications specific to this analysis involved rheumatoid arthritis, osteoporosis, and large subchondral cysts precluding stable anchorage of the implant. The Eclipse implant consists of a titanium rough blasted trunion coated with bonnit and plasma spray, with fins on its back surface preventing rotation of the implant on the bony surface. The trunion is fixed in the metaphysis close to the center of rotation by a self tapping cage screw compressing the trunion onto the resection surface of the proximal humerus. The trunion is additionally supported by the cortical bone. The humeral head is fixed by a cone mechanism on the trunion and is supported by the cortical bone of the resection surface of the proximal humerus. Primary stability is reached by shifting the fixation of the trunion close to the center of rotation, resulting in a short lever arm generating only low shear forces on the trunion and the cage screw.
Eighty-seven patients with a mean age of 58 years at surgery (40 hemi-shoulder arthroplasties (HSA), 47 total shoulder arthroplasties (TSA), 46 female, 41 male) were clinically and radiologically followed-up after a mean of 128 months (range, 105-157 months). 49.4% had previous surgery. Functional results were documented using the age- and gender-normalized Constant score (rel. CS). Indication for shoulder arthroplasty were primary osteoarthritis in 45 cases, posttraumatic arthritis in 47 cases, arthritis due to instability in 11 cases, cuff tear arthropathy in 2 cases and glenoid dysplasia as well as rheumatoid arthritis in one case each.

RESULTS

The rel. CS improved significantly ($p<0.0001$) from 56 points (p) pre-op to 88p post-op. Its subcategories pain (8p pre-, 12p post-OP; $p<0.0001$), ADL (10p pre-OP, 15p post-OP; $p<0.0001$), ROM (20p pre-OP, 28p post-OP; $p<0.0001$) and strength (6p pre-OP, 11p post-OP; $p=0.001$) improved significantly as well.
Results for HSA (mean follow-up 128 months):
- Rel CS: 57p pre-OP, 90p post-OP; $p<0.0001$
- CS pain: 7.8p pre-OP, 11.9p post-OP; $p<0.0001$
- CS ADL: 9.5p pre-OP, 14.5p post-OP; $p=0.001$
- CS ROM: 19.8p pre-OP, 27.5p post-OP; $p=0.001$
- CS strength: 6p pre-OP, 12.2p post-OP; $p=0.01$

Results for TSA (mean follow-up 128 months):
- Rel CS: 55p pre-OP, 87p post-OP; $p=0.001$
- CS pain: 7.9p pre-OP, 12.4p post-OP; $p=0.003$
- CS ADL: 10.4p pre-OP, 14.8p post-OP; $p=0.014$
- CS ROM: 19.5p pre-OP, 28.9p post-OP; $p=0.001$
- CS strength: 6.1p pre-OP, 9.8p post-OP; $p=0.033$

There is no significant ($p>0.05$) difference of pre- and post-op CS as well as its subcategories between HSA and TSA. Clinically and radiologically we observed no loosening of the stemless humeral head component (Fig. 1b,c).

Radiologically, an incomplete radiolucent line of the humeral component was found in 7.9% (6 patients). Four out of the 6 patients had a TSA (8.5) and 2 patients had a HSA (5%). Stress shielding around the humeral component was not detected. Upward migration of the humeral head was observed in 23% (23.7% HSA, 15% TSA, p=0.334). No implant failure was observed at the humeral side. One humeral head replacement was explanted 7 months post-op because of early infection.

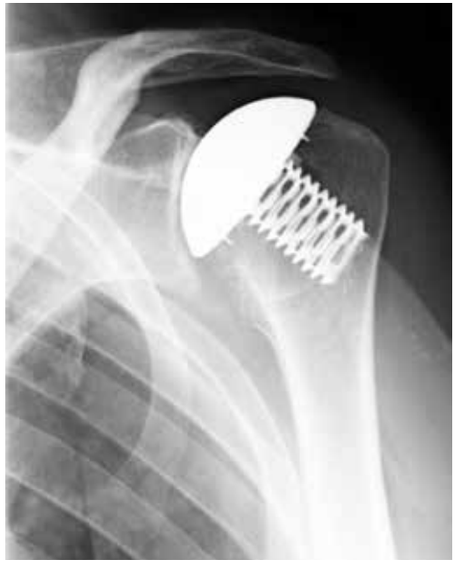

Figure 1b
True ap view 6 months post-op

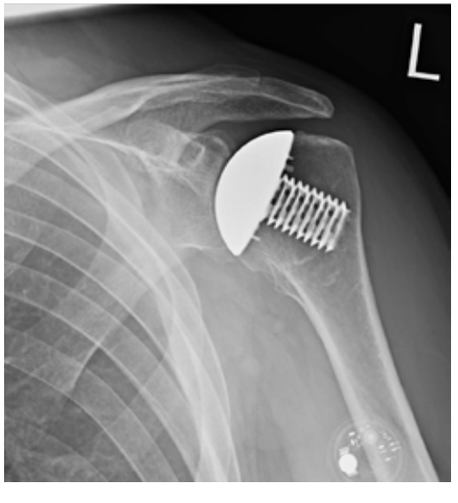

Figure 1c
True ap view 150 months post-OP

18.4% had a rotator-cuff deficiency at follow-up (HSA: 7.5%, TSA 27.7%; p=0.039). Overall, 12.6% of stemless shoulder arthroplasties were revised to reverse total shoulder arthroplasty (5% of HSA, 19.1% of TSA). 8.5% of TSA required an anatomic glenoid replacement. TSA had significantly (p=0.014) more frequently revision surgery than HSA.
Secondary glenoid wear occurred in 64.3% of HSA and none of HSA were converted to TSA. PE-wear was found in 45.5% of TSA. An incomplete radiolucent line < 2mm was observed in 36.4% and glenoid loosening was found in 7.4% of cemented glenoid components. Cementless glenoid components showed loosening in 25% and PE-wear in 15% of the cases.

CONCLUSION

Stemless humeral head replacement showed no loosening with a significant improvement of shoulder function after a mean of 11 years. There is no difference of functional results between HSA and TSA. TSA showed a significant higher revision rate than HSA. So HSA remains a treatment option in patients without glenoid arthritis at the time of surgery.

15/ CLINICAL AND RADIOLOGICAL LONG TERM RESULTS OF ANATOMICAL STEMLESS PROSTHESES

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INTRODUCTION

Shoulder OA is relatively common situation. TSAs provide excellent outcomes in cases of osteoarthritis with a functionnal cuff. For more than 30 years, and under the leadership of Charles Neer, evolutions tend to improve functionnal outcomes and duration of the prostheses (1).
Most of complications are on the glenoid, with frequent loosening. The humeral component needs an optimal positionnement, to restore the geometry of the joint and the balance of the rotator cuff and all the muscles. The main difficulty is to deal with the offsets, especially for the cases of bone distortion or mal union.
Stemless prostheses delete constraints from the offsets, are easier to perform, save bone stock, and will be easier to revise. So The TESS group started the stemless experience in 2003. Their 3 year FU results were good (2). This presentation is the report of the results of the TESS anatomic stemless, with more than 10 years FU.

MATERIAL AND METHODS

This prospective study included 83 stemless anatomic (14 HAs and 69 TSAs) prostheses, performed by the same surgeon (JT) between 2005 and 2008, in 75 patients.
Six patients (9%) had a revision for a glenoid loosening, 15 patients died.
At the end, 48 cases, 10 HAs (TESSc) and 38 TSAs (TESSa : 34 with a PE insert cemented on the glenoid and 4 with PE+metalback), were reviewed. Indications were primary OA in 32 cases, mal union with arthritis in 6 cases, necrosis in 4 cases, post instability arthrosis in 4 cases, rheumatoid arthritis in 2 cases. There were 30 women and 18 men, the mean age was 71 years (22-82) ; The mean FU was 134 months.
The patients provided informed consent for their data to be included in the study.

TESS design (fig.1)

The TESS is a system which allows to perform HAs, TSAs and RSAs. This was the first stem-less prothesis, avalaible in both anatomical and reverse configuration. The stem is always an option.
For the TSA, the concept is based on the anatomic corolla ACo, which is an anchor, made of chrome cobalt, with a titanium plasma spray and full hydroxyapatite coating, available in 4 sizes, and 6 wings for the rotationnal stability. On the glenoid side, both cemented full PE and PE secured on a metalback, are avalaible.

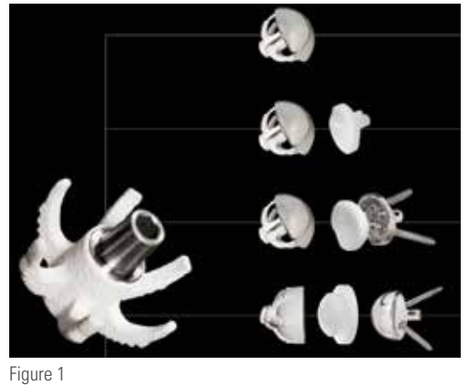


Figure 1
TESS System

Operative technique (fig. 2 and 3)

We used a delto-pectoral approach. For the humerus, the cut was chosen at 135° for the neck shaft angle (NSA) and 30° for the retroversion, and next to the footprint of the superior cuff. Then a pin was placed in the center of the circle between anterior / posterior / superior cortical bone (we payed no attention to the offsets !), and the osteophytes were removed at the inferior part to aligne this circle. We chose the size of the corolla with the « 5 mm rule » around the circle, then passed the drill, used the puncher, chose the diameter of the center head, put the definitive corolla and humeral head.
An HA was used when the glenoid was intact for the cartilage, and a TSA with a cemented PE was used when the glenoid was retroverted (more than 10°), and when the cartilage was poor.
In all cases, the limb was immobilized on a 45° abduction splint for 3 weeks. Passive range of motion started on day 1 postoperatively, and active range of motion started at 3 weeks postoperatively.

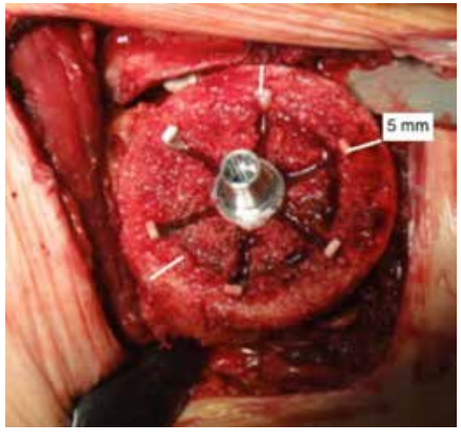


Figure 2
TESSa : 5mm rule

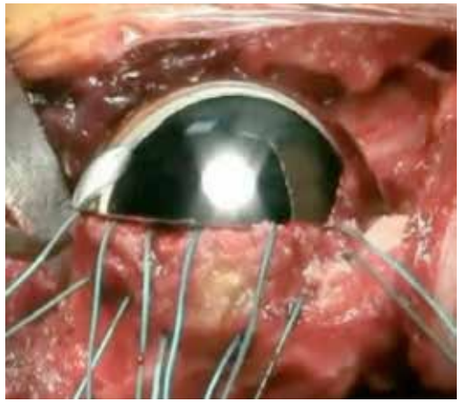


Figure 3
TESSa : anatomical reconstruction

Assessment

Clinical assessment, including visual analog pain scores; range of motion; strength in flexion; and a functional assessment with the Constant score (CS) (3), was performed preoperatively and at the last FU. A determination of patient satisfaction completed the clinical analysis.

The radiographic protocol included standardized, fluoroscopically controlled, anteroposterior radiographs in neutral rotation and adduction views, 1 tangential to the baseplate and 1 tangential to the ACo, as well as a lateral view.
We measured the neck shaft angle NSA. On the humeral side, we created the TESS score, searching for the radiolucent RLL and osteolysis, in 7 zones around the ACo, and 3 grades (<5 mm ; 5-10 mm ; >10 mm), to evaluate the bone modifications and the risk of loosening (fig. 4). For the glenoid, RLL and osteolysis were studied according to the Mole score. The stemless corollas, were specially studied, with 2 criteria, rocking and subsidence, on a superposition of initial and last X-rays.

Statistical analysis

Analysis of variance with a multivariate analysis plus the Wilcoxon signed rank test (for comparison of specific values obtained postoperatively and at last follow-up), the Mann-Whitney U test (for analysis of differences between 2 subgroups), and the Kruskal-Wallis test (for analysis among several subgroups) was used to analyze the data. $P < .05$ was considered significant.

RESULTS (FIG. 4,5,6)

Ninety percent of patients were satisfied or very satisfied. Mean maximal pain was rated as 4 of 15, and 86% of patients had no pain in rest position, but 80% had pain during activities. The final ranges of motion were as follows: flexion, 151° ; abduction, 137° ; external rotation in adduction, 45° ; external rotation in abduction, 66°; and 7 points on the CS scale in internal rotation. Strength in flexion was 4 kg. The mean CS improved from 41 to 75 points. The CS was greater for TSAs than HAs ($P < .05$).

The mean NSA was 138° (125-148). Rocking was 0,04° (0-5), and subsidence was 0,06 mm (0-1) between post-op and last FU.
For the bone modifications, on the humeral side, RLLs were : 86% in zone 1 ; 23% in zone 2 ; 5% in zone 3 ; 18% in zone 4 ; 82% in zone 5 ; 35% in zone 6 ; 26% in zone 7. The TESS score was 98% of stage 1 (no risk of loosening), 2% of stage 2 (possible loosening). There was no evidence of glenoid loosening on TSAs

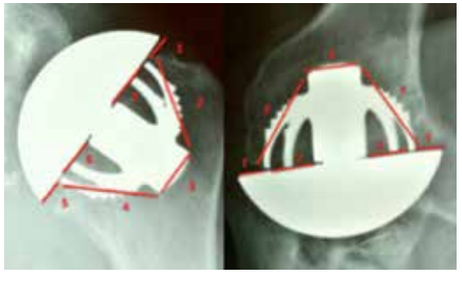
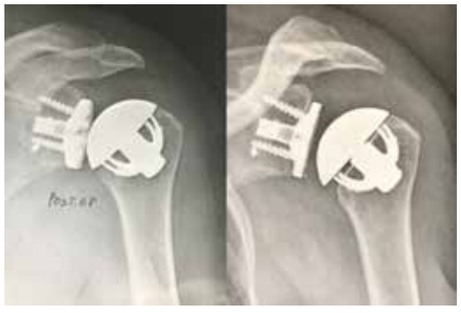


Figure 4
Bone modifications around the ACo : TESS score



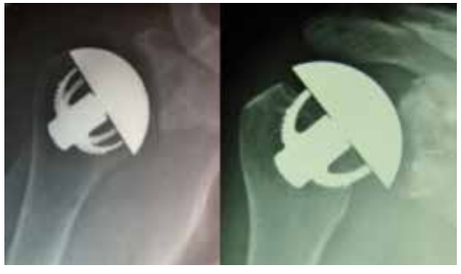


Figure 5 &6
Maximal bone resorptions around the ACo at 10 years FU

DISCUSSION

Shoulder OA is relatively common situation. OA is difficult challenge, in all cases. When the non invasive traitements do not work, prostheses are the best option. HAs and TSAs are common solution to treat OA, necrosis, mal union with arthritis, post instability arthritis (4,5).
The rate of satisfaction is frequently very good (6-9). All the series report improvments for ranges of motion, pain relief, strength, and functionnal outcomes. Long term results are very good when there is no loosening, but the rate of revision is relatively high after 10 to 15 years because of glenoid loosening or wear (10-14). This revision rate can be very high (38%) at 10 years on young patients (15,16). HAs is an alternative solution, but if the glenoid is worn, a TSA is recommended (17,18). There is a big concern on the glenoid side, and we need to develop new designs to improve their survey.
So we need to think about their revision. In all cases, we need to be as less invasive as possible, to save bone stock for the future. In all arthroplasties, the aim is to preserve the bone stock as much as possible. Stemless prostheses are called 4th generation. The experience started with the TESS group in 2003 for the anatomical and 2005 for the reverse.

Stemless TSAs have been fastly accepted because of their reliability and their simplicity. Constraints are on the glenoid. More than 20 series report the good results (19-25). There is no difference with stemmed prostheses. The different stemless TSAs, TESS, Nano, Eclipse, Simplicity, achieved full bone integration despite the differences of their concept of fixation (anchor, cage…). Middle and long term survivorship of the stemless TSAs are excellent on the humeral side, without loosening, and the TESS has stood the test of time (26).
This is the first report for a stemless with more than 10 year FU. Our long term results are in keeping with these previous reports. The TESS stemless provides very good functionnal and radiological outcomes over the time. The improvment of range of motion and functionnal outcomes is comparable to the stemmed protheses, and yield satisfaction. We report no loosening on the humeral corolla, even if bone modifications are progressive with the FU. This resorption is caused by the contact of the metal head, and the reaction with the PE wear. This reaction is equivalent for stemmed prostheses.
The lack of a stem led to interesting findings such as:
- preservation of the metaphyso diaphyseal bone stock.
- better and easier adaptation with anatomic variations.

In most of cases, the cause of the revision is the glenoid, but the difficulty is on the humerus, to extract the first prosthesis because of the stem, and to reconstruct the humeral bone stock. Revisions can be challenging, requiring expansion and osteotomy for extraction of the stem and cement, and the use of a new long stem (27-30). Stemless prostheses can be extracted without big damage, and revisions use a stem less or a standard stem thanks to the diaphyseal bone stock.
The proximal humerus presents anatomical bone variations, involving the inclination angle (NSA), retroversion, medial offset, posterior offset, radius of curvature, and medio lateral angle (31,32). Modular implants are used for a best adaptation. The stemless Corolla demonstrates greater adaptation to local anatomic conditions because the primary fixation is metaphyso epiphyseal and there is not medial and posterior offset constraints. The humeral neck cut needs to be accurate, and after the TESS corolla allows an anatomical reconstruction of the joint with very good outcomes (23). This concept is very interesting in cases of malunion of the proximal humerus, making the surgery easier, with very good outcomes, without osteotomy of the tuberosities (33).

CONCLUSION

The TESS stemless is reliable at long FU. The trend in all arthroplasties is to be less invasive. For all their advantages, and to face the future, we recommend to use a stemless prosthesis.

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16/ ANATOMIC METAL BACK VERSUS FULL POLYETHYLENE WITH MORE 5 YEARS FOLLOW UP

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INTRODUCTION

Total shoulder arthroplasty is a reliable therapeutic option to treat gleno humeral arthritis. Despite the pain relief and the improvement of the function, the weak link of a total anatomic shoulder arthroplasty is the glenoid component. Radiolucent lines around cemented glenoid implants are very common and is varying between 0% and 96% (1,2). By contrast, periprosthetic radiolucent lines around metal-backed glenoid were rare (0 to 25%) (3,4,5,6).
The survivorship of a cemented flat-backed keeled glenoid was 94.5% at 10 years and 79 .4% at 15 years (7). Two arthroplastic systems with a cementless glenoid component: the SMR (Lima LTO, Udine, Italy), the BioModular TSR (Biomet, Warsaw, IN, USA) reported a survival rate of 100% at 6.3 years (8) and 93% at 10 years (9). P Boileau et al in 2002(6) reported a higher rate of failure with a flat metal back stabilized by 2 screws expansion. This author reported a survival rate of 46% at 10 years, with a rate of revision of 37% and an accelerated polyethylene wear in 51%. A possible explanation of this high rate of failure could be explained by the type of fixation of the metalback(expanded screw), the flat surface of the metal back and the number of biconcave or dysplasic glenoids (B2 or C), which reached 50% of the serie.
The registry of the Australian Orthopaedic Association National Joint Replacement (AOANJR) reported in 2018(10) a comparative study of the revision rate of cemented and cementless design glenoid component in conventional total shoulder arthroplasty; They collected during 20 months 10.805 primary conventional TSA. At 5 years, the rate of revision was higher in the cemented group than the cementless group: 3.7% versus 17.9%. The main cause of revision in the cementless group were rotator cuff deficiency (4,4% versus 0.4%), instability (3.8 versus 0.8%) but the rate of glenoid loosening between cementless and cemented glenoid component was similar (1.1%). So, the revision rate in the cementless group was lower if you exclude the SMR glenoid component (LimaCorporate) but was significantly still higher compared with cemented glenoids.
The purpose of this retrospective study was to evaluate the functional and radiologic results obtained in primary osteoarthritis with an anatomic total shoulder arthroplasty through use of 2 different glenoid components: a convex metalback covered with hydroxyapatite and a pegged cemented full polyethylene with a minimum follow up of 5 years.

MATERIALS AND METHODS

Patients selection

We collected in two orthopaedic centers (Lorient (DK) and Paris (PhV) the patients who underwent primary conventional total shoulder arthroplasty (TSA) with an uncemented metalback or cemented pegged full polyethylene glenoid component for primary osteoarthritis. 248 uncemented metal back glenoid component were implanted between November 2003 and May 2012; 98 had more than 5 years of follow-up. Seventeen (17,3%) were excluded: 10 died for medical reasons before 5 years of follow-up and 7 (7.1%) had an incomplete file. Therefore 81 TSAs (Group 1) 56 women (5 bilateral) and 20 men with complete preoperative evaluation, operative records and minimum 5-year follow-up or follow-up until revision were included in the clinical analysis. Between June 1999 and December 2013 we implanted 122 cemented polyethylene pegged glenoid component: 2 patients died, 34 were lost of review and 10 had a follow up less than 5 years. 76 prosthesis (Group 2) were included in the clinical analysis with a complete pre and post op records with more than 5 years follow up.

Implants design (Fig1)

Figure 1

The MB is 6.5 mm thick (3.5 mm of polyethylene and 3 mm of metallic tray). The deep convex surface of the implant and its keel are coated with hydroxyapatite. This is a peer shape with three sizes, an anterior winglet and a keel which both increase the primary stability of the prosthesis. A standard metal back with a long post which perforate anteriorly the fossa of the scapula just below the spine improves the stability of the glenoid component when the bone is osteoporotic or with synovial cyst.
The cemented full pegged polyethylene is 3.5 mm thick. There are four anchors pegs and four sizes with a peer shape to optimize the contact with the peripherical line of the glenoid and a convex back to increase the stability. For the two implants, whatever the size of the humeral head, there is a systematic mismatch between the radius of curvature of the glenoid and of the humeral head with an average of 4 mm (between 1 and 6). This mismatch allows anatomical translation and reduces peripherical constraints and potential glenoid loosening.

The humeral stems were press-fit with careful metaphyseal bone grafting from the humeral head in the medial part of the metaphysis to avoid varus deviation of the stem. The thickness of the humeral head should be less in uncemented glenoid component to compensate the thickness of the metalback (3mm) and to avoid a overstuff joint.

Surgical technique

A deltopectoral approach was used in all patients. Soft tissue dissection was similar to expose the glenoid.
To implant the metal back, we used a specific instrumentation to obtain a good press fit into the bone before to be fixed definitively with two divergent screws size 5.5. In glenoid B1, we reamed anteriorly to correct the retroversion with a little medialization which is useful with the metalback thickness of 6.5mm. In severe glenoid erosion (B2, C) we added posteriorly a cancellous bone graft.

To implant the full pegged PE, we did a soft reaming to keep the subchondral bone and to obtain a perfect adaptation with the convex back glenoid component. 4 sizes allow to cover all the glenoid vault and to be support by peripherical cortical line. The fixation is ensured by a pressurization of the cement into the holes and no cement at the interface implant /bone.(Fig 2).

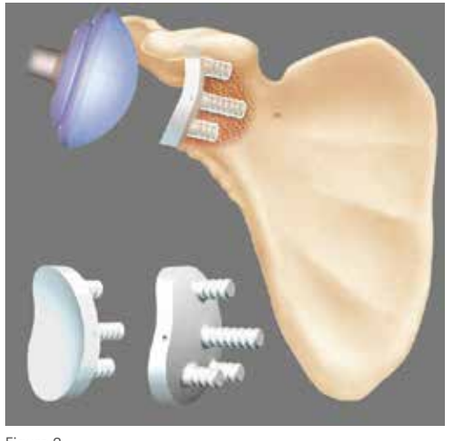

Figure 2

RESULTS

The preoperative clinical evaluation are summarized in table I. There is no significant difference in terms of pain, range of motion, daily activity, strength and shoulder function. The cuff was more frequently torn in the group 2 and the degree of retraction of the tendon (11) and the global fatty infiltration (12) was worst in the group 2 as summarized in the table II. Regarding the deformity of the glenoid, the two series are homogeneous with 35% of posterior subluxation of the humeral head (B1, B2, C).

Table 1
Preoperative clinical evaluation; mean value and range.
w/m women/men; AFE active forward elevation; ER1 external rotation the arm at the side; ER2 external rotation in 90° of abduction; A Cst Absolute Constant and Murley score; SSV functional value of the shoulder; SST simple shoulder test of Matsen.

	N	Age(Y)	w/m	Pain	AFE°	ER1°	ER2°	Strength	A Cst	SSV%	SST
MB G1	81	68(60-76)	56/20	3.5	98	13	20	6	25(14-36)	40	3.5
PE G2	73	67(41- 86)	47/26	3.7	101	17	34	7.3	37(17-58)	40	3.1

Table 2
Preoperative radiological evaluation: Patte, Goutallier and Walch classification: Rupt: rupture; SS Supra spinatus; IS Infraspinatus; SSC subscapularis;GFI global fatty infiltration

	N	Rupt SS	Rupt IS	Rupt SSC	GFI<1	GFI1	GFI2	A1 A2	B1 B2	C
MB G1	81	9	1	0	17%	78%	5%	34 15	12 11	5
PE G2	73	15	4	4	38%	42 %	20%	13 32	20 3	2

Clinical results

In the two groups pain, range of motion and functional score are improved and there is no significant difference between the two groups (Table III).

Table 3
Clinical Outcomes with a FU>5years (60-160 months)

	N	Age(Y)	w/m	Pain	AFE°	ER1°	ER2°	Strength	Constant	SSV%	SST
MB G1	81	68(60-76)	56/20	13	142	44	63	10	70(57-83)		9.73
PE G2	76	67.3(41- 86)	48/28	13.9	151(60 -180)	45	90	10.1	72(18-91)	83(40-100)	9.3(2-12)

Complications and revisions (Fig3)

Figure 3

In the group 1(uncemented glenoid component), 17 patients (21%) had a postoperative complication: Seven complications did not lead to a revision: transitory axillary nerve palsy (2); postoperative humeral fracture (1) at 3 years postoperatively treated successfully nonoperatively; rotator cuff tear (3), dissociation of the polyethylene component from the glenoid baseplate (1). Ten shoulders (12.3%) underwent revision surgery. The causes for revision were: dissociation of the polyethylene component from the glenoid baseplate (4); glenoid loosening at 31 months postoperatively (1); rotator cuff tear (2); instability (3). The 4 cases of dissociation of the polyethylene insert were easily revised by replacing the insert while conserving the metal-backed baseplate. (Fig 4,5,6).

Figure 4

Figure 5

Figure 6

The case of glenoid loosening, the 2 cases of rotator cuff tears and the 3 cases of instability (all 3 patients had a preoperative biconcave B2 glenoid) were all revised successfully to a reverse shoulder arthroplasty. In 2 cases, removal of the uncemented humeral stem was necessary: one case because a first-generation humeral implant (not compatible with the latest-generation humeral bearing) had been used initially, the other one because a small amount of humeral metaphysis had to be cut to allow for final joint reduction. The metal-backed baseplate was conserved in all the cases of revision except for the case of glenoid loosening.

In the group 2, 10 patients (14%) had a postoperative complication; three complications did not lead to a revision: transitory axillary nerve palsy (2) ; postoperative humeral fracture (1) at 6 years postoperatively treated successfully nonoperatively. The causes for the revision of the 7 cases (9,3%) were three rotator cuff tear (SSC + SS) and 4 glenoid loosening. Three glenoid loosening and two rotator cuff tear were revised to a reverse shoulder arthroplasty. One glenoid loosening was revised to an uncemented metal back combined with a bone graft and one rotator cuff tear was repaired with a conservation of the full polyethylene glenoid component.

The final result after the revision was summarized in the table IV. We reported an effective improvement in term of pain relief and functional score, closed to the result of the primary conventional TSA and no significance difference between the two groups.

Table 4
Postoperative clinical evaluation after the revision cases

	N	Age(Y)	w/m	Pain	AFE°	ER1°	ER2°	Strength	A Const	SSV%	SST
MBG112,3 %	10	62	7/3	13	138	50	60	10	65	70	10
PE G2 9,3%	7	59.1	5/2	12.5	148(60-180)	55	60	11	72(18-89)	77.5	10.5

DISCUSSION

Our study shows that TSA with metal-backed uncemented or cemented pegged full glenoid implants leads to satisfactory clinical results at more than 5 years follow up. At a mean 96 months (range 60-160) follow-up, pain, range of motion, Constant score and subjective results were all significantly improved. The rate of revision was higher in the group of metalback (12.3 versus 9.3%) but the rate of glenoid loosening of the glenoid component was higher in the group of full pegged polyethylene cemented (4 cases versus one case). The main causes of the revision rate in the metal back group were a dissociation of the polyethylene from the metal tray (5%), a rotator cuff tear (4%) and an instability (3%). This higher revision rate needs to be counterbalanced by the easiness to convert in reverse shoulder arthroplasty thanks to a universal system. Kany et al (13) reported on 29 cases of revisions using a convertible platform system with a mean Constant Score of 60 at 28 months of follow-up. In our comparative serie, the modularity of our system with a dual platform (Arrow Universal Shoulder Arthroplastic System (FH Orthopedics, Mulhouse, France) proves the easiness of the revision: in 6 cases we shifted successfully to a reverse shoulder arthroplasty with a functionnal score and a pain relief similar to the results of the previous operation (Table IV). So, in the group 2, we revised also successfully

a polyethylene glenoid loosening with a reverse shoulder arthroplasty with similar good results (Table IV); the operation combined a bone graft (from the iliac crest or the coracoid process) or an allograft to restore a good glenoid bone support after removing the polyethylene component and the cement and the implantation of a new metal back glenoid component is not a simpler technique. If we compare with a simple change of the PE on the metal tray, this operation is more aggressive(bleeding), risky (glenoid fracture) and longer for the patient and has to be done by a shoulder surgeon experimented. Valenti et al reported in 2018(14,15) a serie of 13 cases of conversion of uncemented metalback glenoid in conventional TSA in reverse shoulder arthroplasty Intraoperative stability of the implant was satisfactory, and no impingement was found posteriorly, anteriorly, or inferiorly and no per operative complication. In one case, the humeral stem was a first-generation humeral implant which was not compatible with the new generation humeral bearing, and the humeral stem had to be replaced. In 2 cases, reduction of the RSA was either impossible or felt to be too tight, even after extensive soft-tissue release and resection of the remaining supraspinatus. After a mean follow up of two years, the mean Constant Scores improved from 21 (range, 18-32) to 63 (range, 43-90) (P = 0.006) with an improvement of range of motion and pain. A platform system on the glenoid side reduces the operative time of the conversion with a low risk of complications. (Fig 7,8).

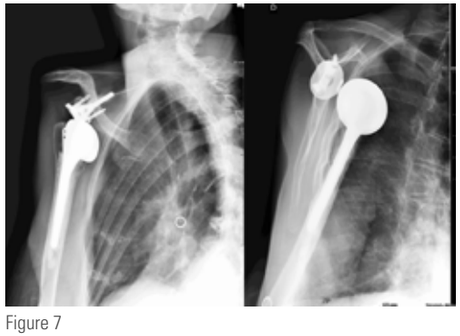

Figure 7

Figure 8

The AOANJR (10) reported at five year follow up a lower rate of revision of cemented glenoid than cementless glenoid(3.7 versus 17.3%): the main causes of revision were in the cementless group were rotator cuff insufficiency (28.2%), instability and/or dislocation (24.3%), breakage of the glenoid insert (12.9%), loosening and/or lysis (7.3%), and dissociation of the glenoid insert (5.5%). Regarding the design of the cementless glenoid component, the higher rate of revision occurred with the SMR glenoid component (Lima Corporate). However, after accounting for the effects of the SMR, this study showed that the remaining cementless glenoid prostheses had a significantly higher revision rate compared with cemented glenoids. The analysis of the various causes showed that the loosening rates between cemented and cementless glenoid components were similar.

Boileau et al (6) in a prospective study comparing 20 metal-backed glenoids with 20 full-polyethylene cemented glenoids found that revision was required in 20% of the metal-backed implants versus 0% in the cemented implants at a mean 38 months follow-up. This higher rate of complications is far from several studies of different metal-backed uncemented arthroplastic systems. The porous tantalum glenoid component (Zimmer, Warsaw, IN, USA) (16) is not a real full uncemented glenoid component because it is partly cemented. However, at a short-term follow-up (20 months, range; 6-24 months), it seems to avoid stress shielding, component stiffness, dissociation, and back side wear. Three arthroplastic systems have been shown to give promising results : the SMR (Lima LTO, Udine, Italy), the BioModular TSR (Biomet, Warsaw, IN, USA) which have been found to have a survival rate of 100% at 6.3 years(3,4) respectively, or the Arrow (FH Orthopedics, Mulhouse, France) which has been found to have a revision rate of 5.59% at 38 months(5).

The complication rate reported by Bohsali et al (17) and Gonzalez et al(18) with more than 5 years FU with cemented full-polyethylene glenoids was 15.8% and 15.6% respectively, little higher than our study with 9.3%. Bonnevialle et al (19) reported on 42 cases of revisions of TSAs by reimplantation of a cemented polyethylene glenoid implant. At a mean 74 months, mean active flexion was 125° with a final Constant Score of 56.7 and glenoid loosening rate of 67%. They concluded that reimplantation of a cemented polyethylene glenoid was not a good option.

We have some limitations in this study. This is not a prospective study and the prosthesis are implanted in two orthopaedics centers by two operators (DK, PV). The surgical technique has evolved during the period of implantation. However it also has several strengths: the cohort of patients is homogenous with the same indication for surgery (primary osteoarthritis). The design of the glenoid implants didn't change during the inclusion period.

CONCLUSION

This retrospective comparative study demonstrates that cementless glenoid components had a significantly higher revision rate than cemented glenoid components. So if you analyse the main causes of the revision, the rate of glenoid loosening is higher in the cemented group (4 and 1 respectively). Dissociation of the PE on the metal tray, instability and rotator cuff tear increase the rate of revision of the cementless glenoid component. The simpler technique of the conversion of anatomic metalback should be counterbalanced with the difficulties of the revision of a cemented glenoid component with a lack of glenoid bone and with a necessary bone graft. We showed that the final functional and subjective results of the revision of the two arthroplastic system were good and similar.

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17/ CLINICAL AND CT SCAN EVALUATION OF AN ALL-POLYETHLENE BI-AXIAL PEGGED GLENOID COMPONENT: FIVE-YEAR MINIMUM FOLLOW-UP

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INTRODUCTION

Primary and secondary glenohumeral arthropathy is an increasingly growing health problem in our common practice, due to an ageing but active population. Total shoulder arthroplasty (TSA) is nowadays the golden standard procedure when treating these pathologies. Anatomic prosthesis has proven to have excellent and good both functional and anatomical results, when it comes to intact rotator cuff osteoarthritis [1, 2].

However, all series published in literature reported that anatomic TSA failed to maintain stable functional results and sufficient durability, at long term follow-ups. Survivorship for anatomic TSA at follow-ups superior to 10 years ranged from 33% to 92% [3, 4]. The main factor for these failures was glenoid component loosening, especially with keeled designs and metal backed non cemented ones [5, 6].

This prompted the designers to develop a specific implant that combines solidity and durability, in order to guarantee stable and lasting functional results over time. In 2001, Wirth and Rockwood [7] proposed a new glenoid component, all polyethylene with biaxial pegs, including a flanged central peg for biological bone-ingrowth fixation and three minimally cemented peripheral pegs (Anchor peg glenoid, Depuy-Synthes).

Since then, many authors studied the reliability of this new component. Results showed an excellent survivorship of the implants and good and stable functional results, at a short and intermediate term [8, 9, 10].

We assessed retrospectively at short-term, mid-term and long-term follow-ups, the functional and CT scan results of anatomic TSA using this Anchor peg glenoid component. The purpose of the study was to evaluate the clinical and radiographic results and confront them to those of the literature, to help us sort out the more reliable and durable implant.

MATERIAL AND METHODS

This series was a retrospective consecutive study involving 40 patients (50 shoulders), operated by the same senior surgeon (A.V) between January 2004 and December 2012, of a glenohumeral osteoarthritis with an intact rotator cuff. Three patients (3 shoulders) were excluded from the study; two patients didn't show up to the first year checkup and one had died of non-related cause. The remaining study group of 37 patients (47 shoulders) had a minimal follow-up period of 12 months.

In order to better analyze the clinical and radiographic evolution, the patients were divided into 3 groups, according to the follow-up period. The first group was the short-term group, named ST group, containing patients followed for at least a period of 12 months, which represents the whole study population, 37 patients (47 shoulders). The second group of patients was the mid-term follow-up group, named MT group, containing patients followed for a period of at least 60 months, 28 patients (37 shoulders). A third group, identified as the long-term group, named LT group, regrouped 14 patients (14 shoulders) who had a minimal follow-up period of 96 months. The remaining 10 patients (16 shoulders) were still being followed.

All patients, in our series, underwent a TSA with an anatomic prosthesis with the Anchor peg glenoid component (Depuy Synthes, Johnson & Johnson, Warsaw, IN, USA), that featured a circumferentially fluted, central, interference-fit peg for bony integration and three small, minimally cemented peripheral pegs (Figure 1).

Figure 1
Anchor Peg glenoid component (Depuy Synthes, Warsaw, IN, USA)

The surgical arthroplasty technique was classic: all procedures were done through a deltopectoral approach with subscapularis desinsertion. The glenoid surface was prepared with a power reamer. Cement was injected using a syringe into the three peripheral peg holes. Cancellous bone was packed between the radial fins of the central peg prior to implantation. All humeral stems were cemented, according to surgeon preference.

Clinical evaluation

Patients were reviewed preoperatively (T0), at 12 months (T1), at 60 months (T5) and at final follow-up (TF). Clinical evaluation was based on the VAS (Visual Analog Score) pain level score. A VAS score of 0 reflected a forgotten pain-free shoulder, while a VAS score of 10 an extremely unbearable pain. Active anterior elevation (AAE), abduction (ABD) and external rotation (ER) were recorded in 10° increments. Internal rotation (IR) was recorded as the highest posterior pelvic or vertebral level reached by the patient's thumb. We also assessed the level and quality of activities. The muscular force was evaluated using cumulative 0,5 kilograms (Kg) weights. We used two functional scores to sum this up, the American Shoulder and Elbow Surgeons (ASES) questionnaire [11] and the absolute Constant score [12].

Radiographic evaluation

All patients had plain shoulder radiographs (AP and lateral views) at T0, T1, T5 and TF; a fine-slice CT scan was performed to all patients at T0 and to 90% of patients at T1 and T5.

Radiological evaluation was done using various classifications. Preoperatively, we used Samilson classification for staging osteoarthritis [13], Walch and Badet classification for staging the glenoid horizontal wear [14], Friedman method to measure glenoid version [15], and Goutallier classification for staging muscular atrophy [16]. At T1, T5 and TF we used the Lazarus classification for staging glenoid loosening and glenoid component seating on plain radiographs [17] and Wirth classification for staging pegs osteointegration [18]. At T1 and T5 we used Yian classification for staging tomographic glenoid loosening [19].

Statistical analysis was done with the statistical software SPSS 22.0 (IBM, NY, USA) to perform paired samples t-tests. A P value of < 0.05 was considered statistically significant.

RESULTS

Clinical results

The typical patient of our series was a sedentary woman in her seventies, suffering from primary glenohumeral osteoarthritis of her right shoulder.

From an epidemiological point of view, the three groups tended to be comparable.

At T0, observed mean ranges of motion were as follow; AAE at 91.3°±30.1, ABD at 81.4°±31, ER at 10.9°±13.2 and in 57.4% of cases an IR at the sacrum level. The mean max weight lifted was 1.1 Kg. The mean ASES score was 32.4±7.8, the mean Constant score was 33.7±9.3 and the mean VAS score was 5.3±2.4.

At T1, there were significant improvements, in the ST group, in all ranges of motion and muscular force. AAE increased by 32.4° ($p<0.001$), ABD increased by 35.5° ($p<0.001$), ER increased by 29.2° ($p<0.001$) and IR leveled up to D12. Maximal lifted weight increased to a mean of 3.9 Kg ($p<0.001$). There were also statistically significant improvements in postoperative ASES, Constant and VAS scores. VAS score decreased by 4.4 points ($p<0.001$). ASES and Constant scores increased, respectively, by 34.6 and 31.5 points ($p<0.001$). Between T1 and T5, of the 37 initially included patients, three of them died, four (5 shoulders) were lost to follow-up, and one patient was excluded from the study due to a quadriplegia, even though his prosthesis was still in place at last follow-up.

In the MT group, there were statistically significant improvements, between T1 and T5, in AAE, ABD and muscular force. A T5, mean AAE was 146.1°±21.8 and increased by 20.7° compared to the T1 value ($p<0.001$), mean ABD was 136.6°±26.6 with an increase of 17.9° ($p<0.001$), mean ER value was 43.1°±7.4 which represented an increase of 2.5° ($p=0.09$) and the mean maximal lifted weight was 4.7 Kg±1.2 which increased by 0.6 Kg ($p=0.02$). Functional scores also increased significantly. ASES score was improved by 7 points, going from 67.5±7.8 at T1 to 74.5±7 at T5 ($p<0.001$) and the absolute Constant score improved by 7.3, rising from 65.8±7.4 at T1 to 73.1±7.1 at T5 ($p<0.001$). Between five and eight years of follow-up, two patients died, two (three shoulders) were lost to follow-up and one patient was out of the study, due to revision with a reverse shoulder prosthesis. Of the initial 40 patients, 24 patients were reviewed at final follow-up.

The mean follow-up in the LT group was 116 months. We noted slight decrease in functional scores associated with an increase in pain score, between T5 and TF, but with no statistical relevance. Mean ASES score decreased from 77.1 to 75.8/100 points, Mean absolute Constant score also decreased from 74.7 to 73.2/100 points whereas Mean VAS score increased slightly from 0.9 to 1.6 points/10 (Figure). AAE and ABD declined also but more significantly by, respectively, 8.6° and 4.2°. ER improved slightly by 0.7°. Maximal lifted weight decreased from 5.1 Kg to 4.7 Kg.

In the LT group, results were compared according to the age. We had 7 cases with ages greater than 75 years. In this sub-group, we found an important decline in ranges of motion but with a stable muscular force, while in the other sub-group of younger patients we found an important drop in muscular force with a slight decrease in ranges of motion (Figures 2 and 3).

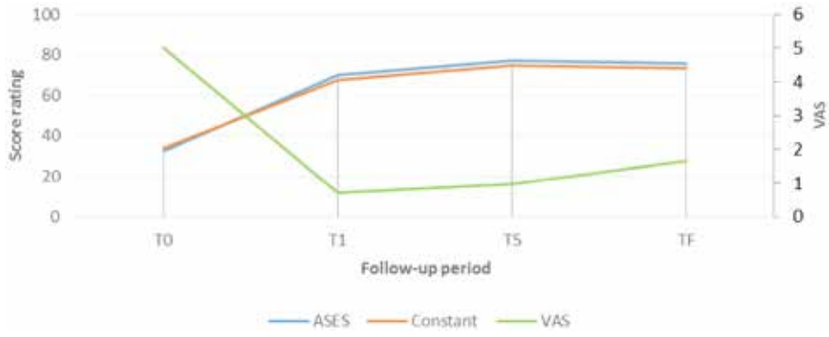

Figure 2
Evaluation of pain and function scores for the LT group

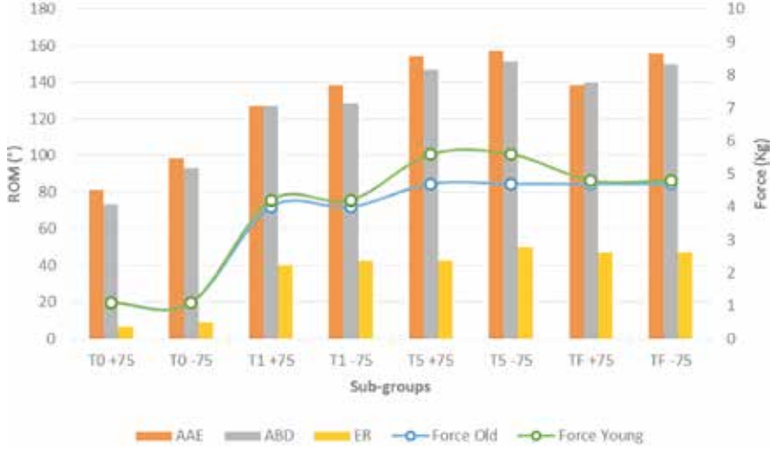

Figure 3
Comparative evolution of ranges of motion and muscular force between old and younger patients

Complications and Revisions

In our series, we had 3 major complications: one intraoperative humeral fracture in a hemiarthroplasty revision, that healed well with a 4 weeks immobilization, and two cases of acute rotator cuff deficiencies following falls, respectively, at follow-ups of 72 and 84 months. The first patient had a subscapularis rupture, which was not re-operated, but she had a bad clinical outcome, with poor Constant (57 points) and ASES (58 points) scores. The second patient underwent revision with reverse total shoulder arthroplasty. On revision, no sign of glenoid component erosion was found. Pathology examination of the pegs showed complete bone tissue integration between the flanges of the central anchor peg.
In our series, we didn't find any case of deep wound infection, or complex regional pain syndrome. No case of dislocation has been reported.

Radiographic results

Humeral component

No radiolucent lines, nor loosening were observed on the shaft part during the follow-up period. For the metaphyseal part, we found osteolysis in four patients at six years of follow-up, due to polyethylene wear. Three of them were men aged from 56 to 69 years, continuing an intensive sport practice despite shoulder overuse prohibition, and a 75-year-old woman, with a progressive wear associated with an evolutive radiolucent line on glenoid side.

Glenoid component

According to Samilson classification, preoperative radiographs showed gleno-humeral arthritis, staged 1 in two cases, staged 2 in 28 cases and staged 3 in 17 cases. Subacromial space was a mean of 8.25 millimeters in height (5-9). On CT scan, mean glenoid version was -2.8°±1.3. Six shoulders had a posterior humeral head subluxation, three of them were greater than 50 %. Thirty two shoulders had concentric glenoid wear (type A1 (11) and A2 (21) glenoid) and asymmetric glenoid wear were observed in fifteen shoulders (type B1 (13) and B2 (3) glenoid). No rotator cuff tears were reported, except for six patients who had a deep partial lesion of supra-spinatus or sub scapularis. According to Goutallier classification, only six patients had a grade 1 or 2 muscular atrophy and one patient, with rheumatoid arthritis, had grade 3 fatty infiltration, without associated tendon tear.

At T1, radiographic and CT scan evaluation showed glenoid implant in neutral position, with a centered humeral head. A perfect glenoid component seating (grade A on Lazarus scale) was observed in 35 shoulders, and a complete osseous integration of the central peg in 36 shoulders, according to Wirth classification.
Forty-three shoulders (91 %) demonstrated a perfect Lazarus score (grade 0). Eleven shoulders had a radiolucent lines on glenoid side. Seven of them were less than one millimeter thick and non evolutive on follow-up, and four were millimetric, with a 2-point Yian score.
We found 35 shoulders associating a grade 0 Lazarus score with a grade 3 Wirth score. There were a statistical relation (p=0,01) between a bad Lazarus score (Lazarus scores > 0) and an incomplete osseous integration of the central peg (Wirth < 3).
At T5, radiolucent lines on glenoid side was observed in nine shoulders. Between T1 and T5, three of them was infra-millimetric and stable, three were evolutive, with worsening in Lazarus score (grade 2) and predominant in the inferior Yian zones, and three radiolucencies newly appeared in that period. Thirty-three shoulders (89 %) remained with a perfect Lazarus score (grade 0).
We found 28 cases associating a grade 0 Lazarus score with a grade 3 Wirth score. There were a statistical relation (p=0,001) between a bad Lazarus score (Lazarus scores > 0) and an incomplete osseous integration of the central peg (Wirth < 3).
At TF, with a mean follow-up of 9.6 years, no glenoid failure was observed in the 14 patients of the LT group. Nine shoulders had a grade 0 Lazarus score (64 %). Between T5 and TF, five shoulders had evolutive radiolucent lines, with grade 2 and 3 Lazarus scores, associated with partial central peg osseous integration (grade 1 and 2 according to Wirth classification).
Ten patients (16 shoulders) were still being followed.

DISCUSSION

In TSA, the choice of implants conditions the durability of the prostheses. The glenoid component is a key element in the shoulder reconstruction surgery. Various types and designs of glenoids were invented, trying to provide answers to the glenoid loosening problems and to the fair and unstable results of anatomic TSA in the long term.
Metal-backed uncemented glenoids were supposed to provide a two-staged stable fixation. First, a primary mechanical fixation with cancellous screws. Then, secondary bony integration of the metal back. Although this sounded seductive, this type of implant showed high rates of failure at short and mid-term follow ups [5]. Compared to all polyethylene glenoid components, metal-backed glenoids had a higher rate of revision procedures for various reasons, such as, osteolysis, screw breakage, metal wear, polyethylene wear, and component dissociation [6]. More recently, new metal backed implants were proposed with several modifications [20] with a deeper convexity implant, hydroxyapatite covered keel, an automatic mismatch of 4 millimeters and a more precise ancillary. Thirty-seven patients were followed at an average of 38 months. Only three revisions were recorded (two rotator cuff tears, one polyethylene dissociation). Significant improve of mobility and pain score were observed and a Constant score rising from 27 to 70 points.
In all-polyethylene glenoid components, the question of using rather keeled or pegged ones was discussed by Lazarus et al. [17]. In a multicenter study of 328 TSA, he reported superior functional results for pegged glenoids versus higher rate of radiolucencies and loosening in keeled ones. The authors also showed that minimally cemented biaxial pegged glenoid components had the best outcome. These results were confirmed by another multicenter study [4] regrouping 518 TSA followed for more than 5 years. They found 32% of glenoid component loosening and 26% of glenoid migration with a cemented all-polyethylene keeled glenoid component.

Clinical evaluation

Since 2002 and the development of the all-polyethylene minimally cemented pegged glenoid component with a flanged central peg, various studies were made (Table 1). All the series in the literature assessed the outcomes of anatomic TSA at mid-term follow-ups. In our series, the study of the MT group revealed, at 60 months follow-up, good and stable functional results between T0 - T1 and T1 - T5, which was in adequacy with results shown in the literature, even if mean ages were much younger than our series. Lower functional results were reported by Parks et al. [21] with a higher rate of revision (8.75% of cases) and a mean Constant score of 69.2 points. Only one patient (1.25%) required revision surgery for aseptic glenoid loosening (three rotator cuff tears, two peri-prosthetic

fractures and one deep infection).
The best functional results were reported by Wijeratna et al. [22] over a mean period of follow-up of 46.7 months.
At long-term follow-up, the functional results in the LT group remained at a good level despite a slight decline in scores but with no significance between T5 and TF, with a mean follow-up period of 116 months. When analyzing these results according to age, we noted that younger patients had a slight loss in ranges of motion but with an important loss in muscular force. On the contrary, older patients had a low but stable muscular force but showed an important decline in ranges of motion. This may be explained by the physiological aging phenomenon of the rotator cuff muscles.
In the literature, there were two main reasons reported for revision with this model of glenoid component. A non-specific one, the infection of the prosthesis and a specific one, the rotator cuff deficiency [3]. In our series, we had two post-traumatic rotator cuff tears, with significant clinical consequence, and no sign of implant loosening was found radiologically and intraoperatively for the revised patient.

Radiographic evaluation

Since 2010, several studies reported radiographic results of total shoulder arthroplasties with this type of glenoid implant (Table 2).

In our series, the median Lazarus score at revision was 0 in 83 % of cases and only four patients had a score greater than 2, ie 13,3 %. In the literature, the rate of radiolucency ranged from 6 to 25% depending on the series, but only 2.6%, ie 7 patients, had a score greater than 2. This small percentage can be explained by a shorter follow-up of these series, which was always less than 5 years [8, 10, 18, 22].
With a mean follow-up of seven years, Noyes et al. [23] reported a complete bone ingrowth of the central peg in 81 % and a component survivorship of 97 %. Only one patient had a revision for aseptic glenoid loosening. They found a correlation between lucent lines around the central peg and the peripheral pegs ; similarly, vault penetration of the central peg is associated with lucent lines around it.

Series	Cases	Mean age *(years)*	Mean follow-up *(months)*	Clinical results *(mean score)*	Revision
Churchill et al. *2010*	20	74.6	67.3	Constant : 80 SST : 11	0
Groh GI *2010*	83	67	34	No functional assessment	0
Arnold et al. *2011*	35	70	43	Constant : 81 SST : 10.3	0
Wirth et al. *2012*	44	66	48	ASES : 84.5 SST : 9.1	1 instability (subscapularis tear)
Vidil et al. *2013*	27	66	48	Constant : 74.5	0
Noyes et al. *2015*	42	64	80	ASES : 82	1 revision (aseptic loosening)
Parks et al. *2016*	76	63.5	28.7	Constant : 69.2 ASES : 84.8	7 revisions 1 aseptic loosening 3 RCT 2 fractures 1 infection
Wijeratna et al. *2016*	83	68.6	46.7	ASES : 97 Oxford : 48	4 revisions 1 RCT 1 aseptic loosening, 1 infection 1glenoid fracture

Table 1
Review of series reporting all-polyethylene minimally cemented pegged glenoid component with a flanged central peg clinical results

Series	Cases	Mean FU *(months)*	Evaluation	Radiolucency *(Lazarus score)*	Osseous integration *(Wirth classification)*
Churchill et al. *2010*	20	67.3	Radiographs + CT scan	Grade 0 : 15 Grade 1 : 4 Grade 2 : 1	Grade 3 : 15 Grade 2 : 2 Grade 1 : 3
Groh GI *2010*	83	34	Radiographs	Grade 0 : 83	Grade 3 : 24
Arnold et al. *2011*	35	43	CT scan	Grade 0 : 32 Grade 1 : 3	Grade 3 : 32 Grade 1 : 3
Wirth et al. *2012*	44	48	Radiographs	Grade 0 : 34 Grade 1 : 9 Grade 5 : 1	Grade 3 : 30 Grade 2 : 11 Grade 1 : 3
Vidil et al. *2013*	27	48	Radiographs + CT scan	/	Grade 3 : 21 Grade 2 : 4 Grade 1 : 1
Noyes et al. *2015*	42	80	Radiographs	Grade 0 : 34	Grade 3 : 34
Parks et al. *2016*	76	28.7	Radiographs	Grade 0-1 : 62 Grade 2-5 : 14	Grade 3 : 38 Grade 2 : 29 Grade 1 : 9
Wijeratna et al. *2016*	83	46.7	Radiographs + CT scan	Grade 0 : 25 Grade 2 : 1 Grade 3 : 1 Grade 4 : 2 Grade 5 : 1	Grade 3 : 68 Grade 2 : 5 Grade 1 : 10

Table 2
Review of series reporting all-polyethylene minimally cemented pegged glenoid component with a flanged central peg radiographic results

Thus, the longevity of this glenoid implant, resulting in a small percentage of radiolucency and the absence of revision for loosening, seems to be correlated to the osseointegration of the central peg, which was complete in 76.5 % of patients in our series.
Similar rates have been reported in the literature ranging from 68 to 91%. Only Groh [10] reported a lower rate, but the evaluation was done on X-rays, which makes it more difficult compared to a CT scan evaluation.
Parks et al. [21] reported, with a mean follow-up of 28.7 months, 14 shoulders (18%) with a Lazarus score greater than 2 and only 38 shoulders (50%) with a complete osseous integration of the central peg (grade 3 according to Wirth classification). These results seems to be a little less good than those observed in the other series and can be explained by a design of the central peg a little different, at the base of the central peg.
The good and long lasting results of our series can be explained by the technical characteristics of the glenoid component with a larger convexity for higher mobility, biaxial pegs for better primary fixation, an automatic mean mismatch of 6 millimeters with lower constraints on the glenoid component [4] and a proved hybrid fixation for the central peg [24], a mechanical one, thanks to the reversely-curved flanges and a biological one, due to the bony integration between the flanges.

CONCLUSION

Anatomic TSA is still suffering from an erroneous poor durability and unstable functional results at medium and long terms. This was caused by poor results reported with old implants, especially metal-backed and keeled ones. Now, with this proven solution for the hybrid fixation of glenoid component, offered by this type of implant, we ought to have durable functional results at longer terms. Finally, maintaining a good rotator cuff musculature, through targeted rehabilitation, especially for older patients, will be the key to a greater longevity with anatomic TSAs.

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18/ MID TERM CLINICAL AND RADIOLOGICAL RESULTS OF AN UNCEMENTED METAL BACKED GLENOID COMPONENT IN TOTAL SHOULDER ARTHROPLASTY

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INTRODUCTION

Total shoulder arthroplasty (TSA) has been proven to lead to significant long-term pain relief and improvement in function for primary osteoarthritis. Despite these satisfactory results, an important rate of glenoid loosening[1, 4, 6, 10, 11, 13, 14, 20, 23, 24,] which is known to impair the quality of clinical results[18, 25] remains a concern. In an attempt to reduce these complications, several authors proposed the use of uncemented metal-backed implants to ensure a strong primary fixation [3,5,6,7,17,21]. These have lead to a high rate of complications at mid-term follow-up. However recent changes in the design of these implants (thinner, without any expansion screw, convex-backed versus flat-backed) have greatly improved the results of such implants (ref letter editor).

We hypothesized that the new design of the MB glenoid implants could be an acceptable option for the management of primary osteoarthritis in terms of pain relief, improvement in range of motion and survivorship.

The aim of this study was to report clinical and radiological results of primary TSAs using an uncemented glenoid implant in primary osteoarthritis with a minimum 5-year follow-up.

MATERIALS AND METHODS

Patients selection

A retrospective review was conducted using a computerized database that contains files of all patients who sustained shoulder arthroplasty performed by one of the surgeons of our group. All patients who underwent primary TSA with an uncemented MB glenoid component between November 2003 and May 2012 for primary osteoarthritis were included. Patients who had incomplete files, less than 3 years of follow-up, other diagnoses or cemented glenoid components were excluded from the study.

In our group 248 TSAs with an uncemented glenoid component were performed during that time period. Among them 98 had more than 3 years of follow-up. Seventeen (17,3%) were excluded : 10 died for medical reasons before 3 years of follow-up and 7 (7.1%) had an incomplete file. Therefore 81 TSAs in 56 women (5 bilateral) and 20 men with complete preoperative evaluation, operative records and minimum 3-year follow-up or follow-up until revision were included in the clinical analysis.

The decision to use an uncemented metal-backed glenoid implant rather than a cemented glenoid was made at the surgeon's discretion.

The mean age (and standard deviation) of the patients was 68 years (±7,9). The right dominant shoulder was involved in 45 cases. Seven patients had undergone previous shoulder surgery : rotator cuff repair (2), acromioplasty or tuberoplasty (5). At the time of surgery, all patients had an intact or repairable rotator cuff.

Mean follow-up was 8 0 months (range ; 36-128 months). All patients were reviewed each year for at least 3 years and retrospectively during 2015 by their own surgeon or by the first author (DK) specifically for this study.

Operative data

A deltopectoral approach was used in all patients. The subscapularis was tenotomized in 60 cases and peeled off the humeral lesser tuberosity in 21 cases (when passive external rotation was limited, in order to allow medial translation of the transeosseous reinsertion). All patients received an Arrow Universal Shoulder Arthroplastic System (FH Orthopedics, Mulhouse, France) with the Arrow metal-backed keeled glenoid implant. The glenoid vault was prepared using specific instrumentation to allow the glenoid implants to be press-fit into the bone. Primary fixation was ensured by 2 axial screws and was enhanced by a third additional anteroposterior screw in 27 cases (33%). This third screw was systematically used at the beginning of our experience, but is now only used in cases of osteoporosis, severe glenoid bone loss or insufficient primary fixation (15/19 cases implanted before 2008 and only 12/62 cases since 2008). In 13 cases of severe glenoid erosion (4 A2 glenoids, 5 B2 and 4 C glenoids[27] cancellous bone graft was added under the glenoid baseplate.

A tenodesis of the long head of the biceps to the pectoralis major tendon was performed in 52 cases, a tenotomy was performed in two and the tendon was left intact in 21 (n=75).

In two cases a long pegged-glenoid component was implanted.

The humeral stems were press-fit in 66 shoulders with careful metaphyseal bone grafting from the humeral head in the medial part of the metaphysis to avoid varus deviation of the stem. In 13 cases, the metaphyseal bone was osteoporotic and the humeral stem was cemented. The humeral component was implanted with 20° of retroversion. Careful repair of the subscapularis was performed in all cases.

Implant design

The MB is 6.5 mm thick (3.5 mm of polyethylene and 3 mm of metallic tray). The deep convex surface of the implant and its keel are coated with hydroxyapatite. In cases where glenoid bone stock may be insufficient a keeled baseplate elongated by a metallic post is available. This post is anchored either anteriorly in the subscapular fossa or posteriorly in the spine of the scapula in order to obtain good fixation. For small or excessively medialized glenoids (i.e. in cases of excessive glenoid wear), a small glenoid baseplate with a shorter and narrower keel (12.6 mm versus 15.2 mm for the standard keel) is available.

Whatever the size of the humeral head, there is a systematic mismatch between the radius of curvature of the glenoid and of the humeral head with an average of 4 mm (between 1 and 6). The design of the implant was modified during the study period (in 2010) because some cases of dissociations between the polyethylene glenoid implant and its baseplate had been reported. A small polyethylene peg was added at the center of the polyethylene glenoid implant in order to obtain an easy and precise positioning of this component before impaction on the humeral tray.

Clinical evaluation

Patients were assessed systematically every year by their surgeon to evaluate level of pain, function and physical exam findings including range of motion. Those who had no clinical evaluation in 2014 were asked to return for clinical assessment by one of the senior authors (DK). Pain was evaluated using visual analog scale (VAS). Active and passive range of motion was recorded in degrees. Function was evaluated using the Constant–Murley score[9], the Simple Shoulder Test (SST)[19]. Subjective satisfaction was assessed by asking patients at follow-up how they felt compared with before surgery and was graded using a 4-point scale : 1 = much better ; 2 = better ; 3= same ; 4 = worse .

Radiological evaluation

Four standardised views of the shoulder were used for radiographic analysis pre- and post-operatively. These included axillary and anteroposterior radiographs, with internal, neutral and external rotation of the humerus. Particular attention was paid to be strictly perpendicular to the glenohumeral joint space in order to detect a narrowing which would mean that there is polyethylene wear therefore all radiographs were made under fluoroscopic control.

An arthro CT-scan was also ordered to assess preoperative glenoid morphology according to the method of Walch et al.[27] and to evaluate the status of the rotator cuff. Retraction of the tear was classified according to the Patte classification[22] and fatty degeneration according to the Goutallier classification[15]. Preoperatively the Walch classification was available for 77 cases (95%) : A1 (34) ; A2 (15) ; B1 (12) ; B2 (11) ; C (5). Therefore 35% of the cases had posterior subluxation of the humeral head. According to the Goutallier classification the global fatty degeneration index evaluated on CT arthrography was <1 for 14 shoulders (17%), 1 in 63 patients (78%) and 2 in 4 patients (5%) . The supraspinatus tendon was torn in 9 cases and the subscapularis muscle was torn in 1 case. There was no rupture of the infraspinatus.

Postoperative radiographs were reviewed to evaluate glenohumeral subluxation, polyethylene wear, dissociation of the polyethylene component and periprosthetic lucency.

PE wear was assessed by comparing postoperative radiographs at last follow-up to immediate postoperative films and narrowing of the glenohumeral joint space was graded as follows : 0, no narrowing ; 1, partial narrowing (no contact between the humerus and the baseplate) ; 2, complete narrowing (contact between the humerus and the baseplate)[3].

The presence and extent of periprosthetic lucency was graded as follows : 0, none ; 1, 1 mm incomplete ; 2, 1 mm complete ; 3, 1.5 mm incomplete ; 4, 1.5 mm complete ; or 5, 2 mm complete. Glenohumeral subluxation was evaluated with regard to direction and degree and was graded as follows : none, mild (center of prosthetic head translated <25% relative to center of glenoid component), moderate (center of prosthetic head translated 25%-50% relative to center of glenoid component), or severe (center of prosthetic head translated >50% relative to center of glenoid component).

Dissociation of the polyethylene component was diagnosed on radiographs or intraoperatively at the time of revision.

Statistical analysis

Descriptive statistics are reported as mean (range) for continuous measures and number (percentage) for discrete variables. The Student's t-test was used for statistical analysis when two groups had to be compared. When the comparison involved more than two groups, a variance analysis was applied. The alpha level for all tests was set at 0.05 for statistical significance.

RESULTS

Complications and Revisions

Three patients had an intraoperative complication : humeral fracture (1) treated immediately by cerclage, fracture of the anterior rim of the glenoid (2) which healed uneventfully. Seventeen patients (21%) had a postoperative complication. Seven complications did not lead to a revision: transitory axillary nerve palsy (2) ; postoperative humeral fracture (1) at 3 years postoperatively treated succesfully nonoperatively; rotator cuff tear (3), dissociation of the polyethylene component from the glenoid baseplate (1). Ten shoulders (12.3%) underwent revision surgery. The causes for revision were : dissociation of the polyethylene component from the glenoid baseplate (4) ; glenoid loosening at 31 months postoperatively (1) ; rotator cuff tear (2) ; instability (3). The 4 cases of dissociation of the polyehtylene insert were easily revised by replacing the insert while conserving the metal-backed baseplate.

The case of glenoid loosening, the 2 cases of rotator cuff tears and the 3 cases of instability (all 3 patients had a preoperative biconcave B2 glenoid) were all revised successfully to a reverse shoulder arthroplasty. In 2 cases, removal of the uncemented humeral stem was necessary : one case because a first-generation humeral implant (not compatible with the latest-generation humeral bearing) had been used initially, the other one because a small amount of humeral metaphysis had to be cut to allow for final joint reduction. The metal-backed baseplate was conserved in all the cases of revision except for the case of glenoid loosening.

Clinical Results

Pain

TSA was associated with a significant improvement in pain scores from a mean 9.5 ± 1.17 points preoperatively to a mean 1.4 ± 2.15 points postoperatively (p<0.0001).

Range of Motion

Active anterior flexion improved significantly from a mean 98° ± 28° preoperatively to a mean 142° ± 31° postoperatively (p<0.0001). Active external rotation with the arm on the side improved significantly from a mean 13° ± 13° to a mean 44° ± 26° (p<0.0001). Active external rotation with the arm at 90° of abduction improved significantly from a mean 20° ± 21° preoperatively to a mean 63° ± 23° postoperatively (p<0.0001). On the average, internal rotation improved significantly from a 13° ± 12° to 39° ± 20° (p<0.0001).

Functional Scores

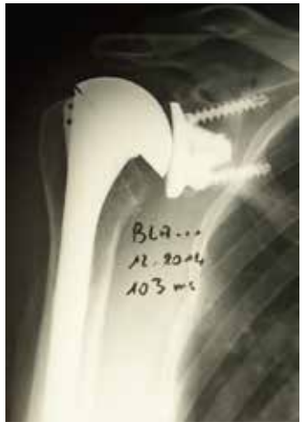
The absolute Constant-Murley score was significantly improved from 25.4 ± 11 to 69.5 ± 13.3 (p<0.0001). The weighted Constant-Murley score was also significantly improved from 34.9 % ± 15.3 to 98% ± 18.5 (p<0.0001). At the time of latest follow-up, mean SST was 9,73 yes (n= 60). Eighty-seven percent of the patients felt they were better or much better than pre-operatively.

Radiological Results

On the most recent radiographs, moderate superior subluxation was seen in 4 patients, severe superior subluxation in 3 patients, severe posterior subluxation in 3 patients.

At the time of the most recent follow-up, no glenoid periprosthetic lucency was present and no shift in position of the glenoid implant was observed. In 4 cases the inferior glenoid screw was out of the pillar but this was not associated with any clinical consequence. PE wear was graded 1 in 3 cases with partial narrowing of the glenohumeral space (Fig. 1) and graded 2 in 1 case with complete narrowing of the glenohumeral space without deformation of the metallic baseplate (Fig. 2).

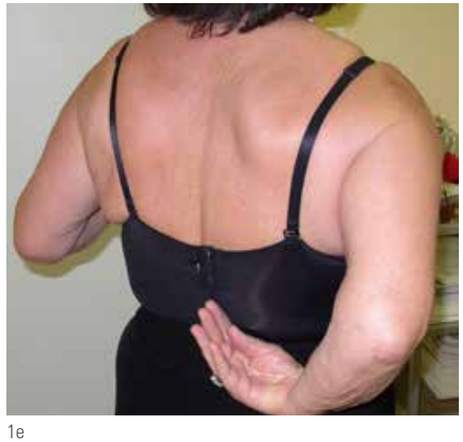
1a



1b

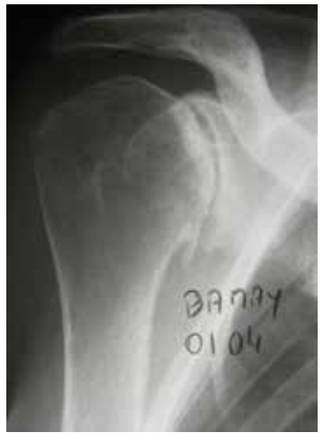
1c

1d

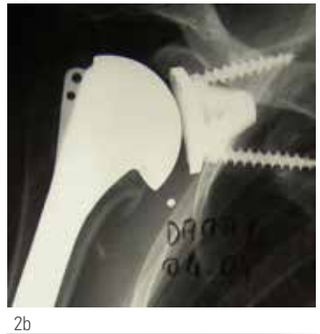


1e

Figure 1
Anteroposterior radiograph of a right shoulder at 103 months of follow-up showing partial narrowing of the gleno-humeral joint space (a). However, the shoulder remained pain-free with good range of motion. The Constant score was 85 (129%)
-1a : preoperative Xray
-1b : last xray 103 months
-1c : active elevation
-1d : active lateral rotation at 90° of abduction
-1e : active medial rotation



2a



2b

2c

Figure 2
Patient operated in 2004. At the last follow up of 128 months. The radiographs showed a complete narrowing of the gleno humeral joint without clinical repercussion . She was 80 years old a t the last review with no pain, SSV at 80%, ADL at 20, active flexion at 150°, and a final Constant score at 76
2a : initial radiograph
2b : immediate post operative radiograph
2 c : final radio at 128 months

Humeral periprosthetic lucency was present in 2 shoulders at the time of the most recent follow-up. The lucency was grade 3 in those 2 cases. No shifts or subsidence of the humeral component were found. In 4 cases, osteolysis of the medial part of the humeral metaphysis was observed. Four uncemented humeral stems were slightly malpositionned : 2 in varus and 2 in valgus without any functional consequence.

DISCUSSION

Our study shows that TSA with metal-backed uncemented glenoid implants leads to satisfactory clinical results at mid-term follow-up. At a mean 80 months follow-up, pain, range of motion, Constant score and subjective results were all significantly improved. Radiological results were equally satisfactory as only 4 cases (4.9%) of polyethylene wear (Fig 1) were found with only 1 complete narrowing of the joint space (Fig 2) with contact between the humerus and the baseplate with no clinical consequence. Only one case (1.2%) of glenoid loosening was found. This is far less than what has been recently reported by Boileau et al.[3] who found 51% of polyethylene wear and 19% of glenoid loosening at a mean 8.5 year follow-up. However, our findings are in agreement with sveral studies of different metal-backed uncemented arthroplastic systems. The porous tantalum glenoid component (Zimmer, Warsaw, IN, USA)[21] is not a real full uncemented glenoid component because it is partly cemented. However, at a short-term follow-up (20 months, range ; 6-24 months), it seems to avoid stress shielding, component stiffness, dissociation, and back side wear. Three arthroplastic systems have been shown to give promising results : the SMR (Lima LTO, Udine, Italy), the BioModular TSR (Biomet, Warsaw, IN, USA) which have been found to have a survival rate of 100% at 6.3 years[5] and 93% at 10 years[7] respectively, or the Arrow (FH Orthopedics, Mulhouse, France) which has been found to have a revision rate of 5.59% at 38 months[17].

The complication rate in our series was 21% which is higher than what has been previsously reported by Bohsali et al.[1] and Gonzalez et al.[14] with cemented full-polyethylene glenoids (15.8% and 15.6% respectively). The revision rate in our study was 12.3%. Boileau et al.[2] in a prospective study comparing 20 metal-backed glenoids with 20 full-polyethylene cemented glenoids found that revision was required in 20% of the metal-backed implants versus 0% in the cemented implants at a mean 38 months follow-up. However, this higher reveision rate needs to be counterbalanced by the easiness with which these are performed thanks to a universal system and by the good results they give[16]. Kany et al.[16] reported on 29 cases of revisions using a convertible platform system with a mean Constant Score of 60 at 28 months of follow-up with no signs of early loosening. We also found good results after revision in our series (Table 1) with a mean active elevation of 138° and a mean Constant Score of 65 at a mean follow-up of 22 months after revision. The sole replacement of the polyethylene glenoid insert was found to be very straightforward and was always possible as opposed to what has been reported by Boileau et al.[3] who were able to reinsert a new polyethylene component in only 2% of the cases probably because of important glenoid bone loss. In our series, revision was always simple and limited to the replacement of the humeral head and polyethylene insert (preserving the humeral stem and the glenoid baseplate) except in 3 (30%) cases (2 stem replacements and 1 baseplate replacement). Bonnevialle et al.[4] reported on 42 cases of revisions of TSAs by reimplantation of a cemented polyethylene glenoid implant. At a mean 74 months, mean active flexion was 125° with a final Constant Score of 56.[7] and glenoid loosening rate of 67%. They concluded that reimplatation of a cemented polyethylene glenoid was not a good option.

Despite a relatively high revision rate (12.3%), absolutely no glenoid periprosthetic radiolucent lines were observed at the time of last follow-up (Figure 3).

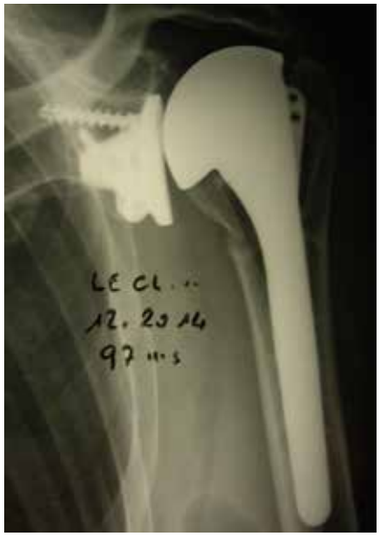


Figure 3
Post operative radiograph from a patient of 81 years old man operated in 2006. He sustained a peroperative fracture of the glenoid rim which was well stabilized thanks to the anterior winglet. The glenoid implant was fixed a little bit low without inferior screw. The saggital screw was able to stabilize the base plate. With a follow up of 97 months, there was no narrowing of the GH space, and the clinical result was very good, no pain, active elevation at 150°, ER1 at 20°, ER2 at 50°, Constant score at 74 (101%), SSV at 80

On the other hand, progressive radiolucent lines are systematically seen with cemented polyethylene implants and their progression is known to be associated with a deterioration of the Constant Score[8, 12, 18, 26]. These radiolucent lines remain asymptomatic for a long period of time, however when patients start to become symptomatic and painful, major glenoid bone loss can be found. The only therapeutic option for these painful and often elederly patients is a complicated revision procedure with glenoid reconstruction. Therefore metal-backed glenoid implants could prevent these challenging situations. A partial osteolysis of the medial metaphyseal humerus part is frequentely associated with a narrowing of the GH joint probably caused by a polyethylene wear. This erosion occured also with a PE glenoid component and in any case in our serie was responsable of humeral loosening or pain at the last FU .

Our study has several limitations. It is a multicentric retrospective study at a mid-term follow-up without any control group. The study period is long and our surgical technique and indications have evolved over that period of time. However it also has several strenghts, the cohort of patients is homogenous with the same indication for surgery (primary oseoarthritis) and low rate of patients lost to follow-up (7.1%). The same kind of implant was used for all patients and the number of patients was relatively large with a clinical and radiological follow-up of minimum 3 years.

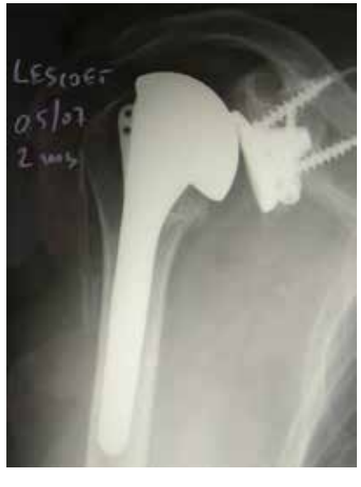


Figure 4
Patient operated at 67 years old presented a dissociation of the PE liner at 2 months which was simply changed and reimpacted. The PE liner can be seen just under the humeral head With a follow up of 5 years the revision gave a very good result with a final flexion at 170°, and a Constant score at 83(109%)

CONCLUSION

The use of a metal-backed glenoid implant in a series of TSAs for primary osteoarthritis led to satisfactory clinical and radiological results. The complication rate was found to be higher than what has been reported with cemented glenoid implants, however we have not observed the high rate of polyethlyne wear described in recent series (2,3). In addition, the concept of universal platform system was found to simplify revision procedures by preserving the humeral stem and the glenoid baseplate. Therefore, an uncemented metal-backed glenoid implant appears to be a viable option in TSA for primary osteoarthritis.

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	Pain	ADL	Flexion	ER2	Strength	Constant	Constant %
Non-revised (n=6)	13,2 (5-15)	18,58 (13-20)	135° (40-180)	68,5° (10-95)	6,45 (0-17)	68,3 (39-87)	100,1 (60-129)
Revised (n=33)	13.3 (5-15)	17.7 (11-20)	138.3° (90-170)	53,3° (0-80)	7,5 (2-17)	65,3 (32-90)	90,8 (45-111)
p-value	0,94	0.56	0.80	0,31	0.66	0.74	0.41

Table
Comparison of the functional results between the non-revised cases (follow-up: 65months; range 36-128 months) and the revised cases (follow-up 53 months, range 36-109 months). (ER2: external rotation at 90° of abduction, Constant %: weighted Constant score) The cases which have revised have the same results than the cases without revision, thanks to the simplicity of the revision with a convertible system.

19/ OSTEOARTHRITIS WITH FUNCTIONAL CUFF ; WHICH HUMERAL COMPONENT DO YOU PREFER ? I PREFER A STEMLESS SCREW IN SYSTEM

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BACKGROUND

Stemless total shoulder arthroplasty is a well-established and reliable surgical treatment option for glenohumeral osteoarthritis resulting in loss of pain and improvement of shoulder function. Currently there are two methods for the fixation of the humeral component. The purpose of this study is the clinical and radiological comparison of two different stemless designs (impaction vs. screw fixation) for total shoulder arthroplasties in patients suffering from primary glenohumeral osteoarthritis.

METHODS

A retrospective cohort study including 39 patients with a mean age of 67 years and a minimum follow-up of two years was performed. Patients were separated into two groups based on the selected implant. In group A (n = 21) an impaction type design (Figure 1 a-f) and in group B (n = 18) a screw fixation design (Figure 2 a-f) was used. For clinical examination the Constant-Murley-Score (CS) and Subjective-Shoulder-Value (SSV) were evaluated. Radiological examination was performed on true-AP, axial and Y-view radiographs.

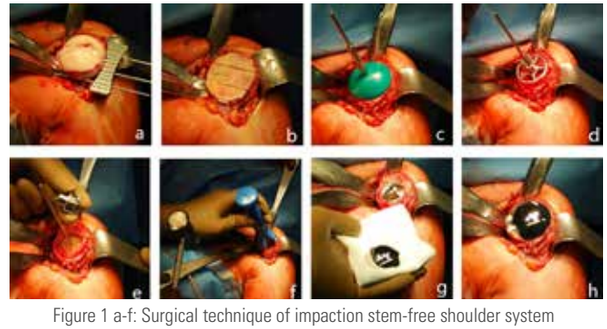

Figure 1 a-f: Surgical technique of impaction stem-free shoulder system

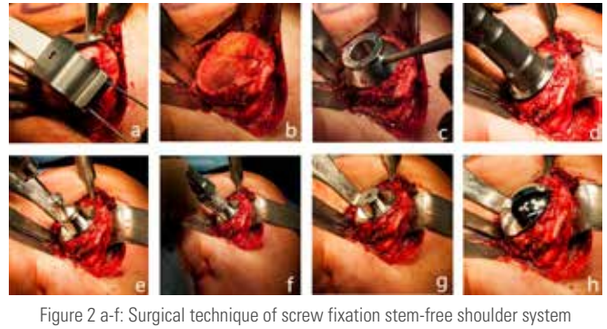

Figure 2 a-f: Surgical technique of screw fixation stem-free shoulder system

RESULTS

In group A the CS increased from 29.0 to 72.6 points and SSV from 33.1 to 85 % ($p<0.05$). In group B the CS increased from 27.1 to 65.2 points and SSV from 27.3 to 76.7 % ($p>0.05$). In group A osteolysis/subscidence of the medial calcar was present in seven patients (Figure 3).

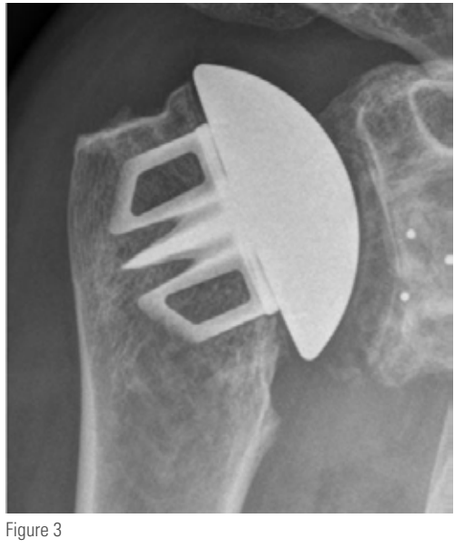

Figure 3
Impaction stem-free shoulder system with resorption/osteolysis of the medial calcar

In group B no osteolysis/subscidence of the medial calcar was found (Figure 4). There were no signs of osteolysis. No signs for humeral loosening was found in both groups.

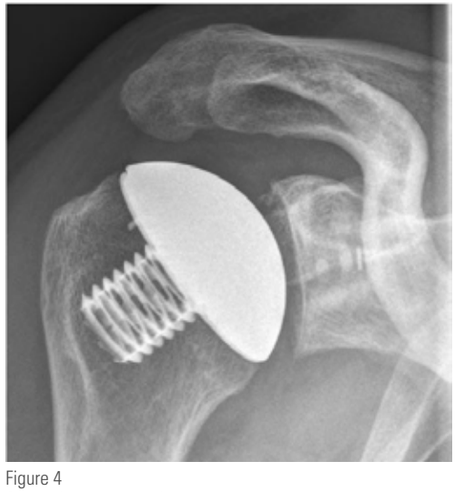

Figure 4
Screw fixation stem-free shoulder system without resorption/ osteolysis of the medial calcar

CONCLUSION

Impaction and screw fixation total shoulder arthroplasty for primary glenohumeral osteoarthritis using a stemless device provide reliable clinical results. The screw fixation seems to prevent osteolysis/subscidence of the medial calcar. We currently have two hypotheses: It might be a result of a biological reaction to a polyethylene wear of the glenoid component or impingement of the implant against the medial calcar (humeral notching). We used fully cemented keeled glenoids from each company with both designs. The other hypothesis is that this is the result of an uneven load distribution on the humeral bone. The screw fixation including the baseplate might distribute the load evenly leading to constant rim loading resulting in less bony resorption. The load in the impaction system is conducted through the anchor and from there to bone.

20/ WHY I PREFER AN ON-LAY HUMERAL TRAY COMPONENT WHEN PERFORMING REVERSE SHOULDER ARTHROPLASTY

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INTRODUCTION

Since the introduction of the Reverse Shoulder Arthroplasty (RSA) by Grammont for CTA in 1993, many material and technological improvements have been developed to improve results. Grammont's original design was based upon a medialized center of rotation of the glenosphere in order to improve fixation into the glenoid. The humeral component was an inlay epiphyseal component that created a relative medial position of the humerus as well.

Since that original design Frankle and others have advocated for more lateralized glenosphere reconstructions to improve soft tissue tensioning while improving ROM in the face of better implant designs and improved biomaterials for better fixation.

As an outgrowth of these developments, we developed a system with convertible humeral components for the humerus from an original anatomical total shoulder arthroplasty (TSA) system. This system was based upon creation of an on-lay humeral tray and polyethylene cup liner. Since the humeral stem was a 45 degree head shaft angle this placed the humeral tray liner 135 degrees well more vertical than the very horizontal 155 degrees of the original Grammont design.

This more vertical design effectively lateralizes the humeral component thereby improving deltoid function, external rotator strength and overall impingement free motion. It also minimizes the occurrence of scapular notching a well-reported finding and possible complication of the original Grammont design implant.

It is for each of these reasons of component convertibility and humeral lateralization that I choose an On-lay humeral tray component when performing RSA.

Lateral Humeral Offset in RSA

The original design of Grammont was based upon the concept of a medialized glenosphere design which was predicated on increasing compressive loading on the glenoid surface thereby obtaining the best possible fixation of this first generation glenosphere component. In the ensuing years better biomaterials and baseplate component designs have improved implant fixation. Additionally, Frankle others have demonstrated that a more lateralized glenosphere component would improve deltoid rotator cuff function and range of motion and limit scapular notching a significant complication of the original Grammont design.

For this reason many of the more contemporary designs have included systems in which the Glenosphere could be lateralized based upon the design of the metallic glenosphere components. More recently, Boileau and others have advocated for the use of a BIORSA humeral head auto graft technique to lateralize the glenosphere.
Previously, Roche et al did finite element analysis studies of different implant configurations to predict the best functional outcomes after reverse shoulder arthroplasty without sacrificing implant component fixation. In this study, they evaluated four different component configurations and compared the results. This included a component configuration with a medialized glenosphere and the medialized humeral component, a medialized glenosphere and lateralized humeral component and, a lateralized glenosphere and medial humeral component and a lateral glenosphere with lateral humeral component.
Their conclusion was that in terms of ROM and proper soft tissue tensioning the lateralized glenosphere and lateralized humeral component gave best results.
Berhouet et al have shown that a lateralized humeral component improved impingement free ROM while limiting scapular notching.
Giles et al (Athwel) did similar cadaveric studies and reported that laterized humeral component with medial glenosphere was best model for function and implant fixation and durability.
Two recent clinical studies by Helmkamp et al. and Merolla et al. have indicated in medium length follow-up studies that lateralized humeral component designs performed better than inlay or medial humeral component systems.
At present, we feel that a lateralized humeral component system gives the best clinical and functional outcome for our patients. The system which we utilize exclusively is an on-lay humeral tray with polyethylene liner system has

multiple thickness which creates a neck shaft angle of 135 degrees and results in lateral humeral offset with any thickness combination (Fig 1).

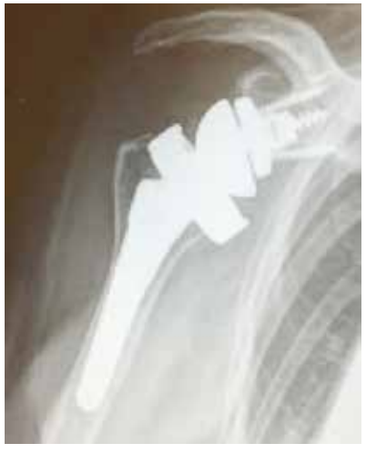

Figure 1
Onlay Humeral Tray and Liner Component (Comprehensive © Reverse Total Shoulder, ZimmerBiomet, Warsaw ,Ind.) Onlay humeral tray/liner component lateralizes humerus improving deltoid and external rotator function while being convertible if a prior Arthroplasty required revision

Convertible Humeral Stem Components

Clearly, convertible humeral components when they can be utilized facilitate revision shoulder arthroplasty surgeries. By reducing surgical time and exposure, limiting potential blood loss and by obviating the need to remove a well-fixed humeral and/or glenoid components which may lead to periprosthetic fracture complications these implants can facilitate any revision cases. There are some drawbacks to convertibility which must be recognized in revision cases of TSA or HA to RSA and these include situations where the index procedure component is too proud to allow reduction of RSA or too retroverted to allow for impingement free ROM. In most reported series of the use of convertible humeral components simple conversion of the convertible stem in more than 75% of patients (Fig 2)

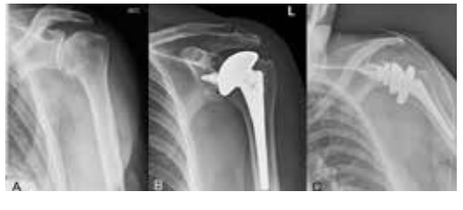

Figure 2
On-lay Humeral component can be more easily revised in many cases because convertibility can diminish complications of removing a well fixed stem. A Primary OA. B. Index anatomic TSA. C Revised with convertible On-lay component without stem removal after subscapularis rupture and instability

As described in a previous chapter in this book, I prefer to use a convertible humeral component system whenever possible. However, one should not compromise the index shoulder arthroplasty for the sake of revision in considering implant height and version.

CONCLUSION

On-lay type humeral components for different shoulder implant systems afford the surgeon the ability to lateralize the humerus thereby improving deltoid and rotator cuff function while improving impingement free ROM and avoiding scapular notching.
These On-lay type systems are inherently convertible within the limits of humeral stem positioning at the index arthroplasty. This convertible aspect simplifies revision surgery in many cases with shorter OR time, less blood loss, and fewer complications including possible humeral fracture in removing a well fixed humeral stem.
These findings of better humeral laterality with a more vertical neck-shaft angle and component convertibility make On-lay humeral tray and liners my component of choice in RSA.

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21/ OSTEOARTHRITIS WITH FUNCTIONAL CUFF WHY I STOP TO IMPLANT A RESURFACE PROSTHESIS?

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The objective of our study was to evaluate clinical and radiological results of all our resurfacing hemiarthroplasty cases performed during a 7-year period. Our hypothesis was that resurfacing induced an increase lateral offset that could be at the origin of an overstuffing of the joint with glenoid wear and rotator cuff thickening. This early wear lead to decrease functional results and decrease survival rate.

INTRODUCTION

Resurfacing humeral prosthesis has been introduced by Copeland in the 90's and was used since 10 years in a large spectrum of degenerative lesions of the shoulder[10]. Many studies have reported satisfactory short-term results comparable to stemmed prosthesis [1, 2, 9, 11, 15]. A recent assessment of resurfacing prosthesis in primary osteoarthritis reported well restored anatomy, increased lateral offset of the humeral head, a tendency towards varus implant positioning and a long-term trend towards glenoid wear [12].
In 2017, the data from the Australian Registry recorded that the nine-year cumulative percent revision of primary stemmed hemi arthroplasty and hemi resurfacing was 10.5% and 15.1% respectively. Hemi resurfacing has a lower rate of revision in the first 1.5 years, however after 2.5 years the revision rate was higher than stemmed hemi arthroplasty[3].
The data from the Danish Registry have shown a five-year cumulative revision rate of 9.9% for resurfacing hemiarthroplasties vs 7.2% for stemmed hemiarthroplasties Rasmussen. This difference was however not statistically significant. The most common indications for revision following resurfacing hemiarthroplasties were glenoid attrition and rotator cuff dysfunction. Same data were reported by the Norwegian Registry with cumulative rates of revision of approximately 6% and 17% after 5 and 10 years, respectively[5]. Finally, the latest published annual report from New Zealand recorded a twelve-year cumulative rate of revision of approximately 12.7% with a higher incidence on patients younger than 55[20].
In 2014, 41 resurfacing shoulder arthroplasties were compared to 37 stemmed hemiarthroplasty and were reviewed with minimum 2-year follow-up. At a mean of 44 months follow-up, there was no significant differences in functional scores. However, survivorship without revision was significantly poorer in the resurfacing group, with 4 revision procedures for glenoid wear (9.8%) versus none in the hemiarthroplasty group[7].

MATERIALS AND METHOD

Patients

We conducted a single-center retrospective study in our department that included all patients treated for shoulder osteoarthritis using resurfacing hemiarthroplasty, whatever the etiology, between 2005 and 2013, with a minimum follow-up of 2 years.

100 patients were included and followed up for a mean of 5 years. There were 47 women and 53 men, of 58 years old on average (range, 29-84). Fifty-five cases were related to primary osteoarthritis. The 2 other main etiologies were post-traumatic and post-instability osteoarthritis.

According to Walch classification, Glenoid wear was of type A in 60 cases (A1=46, A2=14), of type B in 35 cases (B1=27, B2=8), of type C in 3, and related to anterior subluxation in 2.

There was no important fatty infiltration of the rotator cuff with an average fatty degeneration index of 1.16.

Method of evaluation

The principal assessment criterion was the clinical results with pain, Constant score, Quick-DASH score, Neer score and Simple Shoulder Value (SSV). Active range of motion, complication, revision were also analyzed.
The secondary assessment criterion was the radiologic measurement of the implant positioning and its evolution with the time. Using anterior-posterior view and axillary view we analyzed: humeral head diameter (HD), humeral head height (HH), glenoid depth (GD), proximal migration of the humerus (PM), humeral shaft angle (CCD), acromio-humeral distance (AHD), and the lateral offset (LO) (Figure 1) (Figure 2).

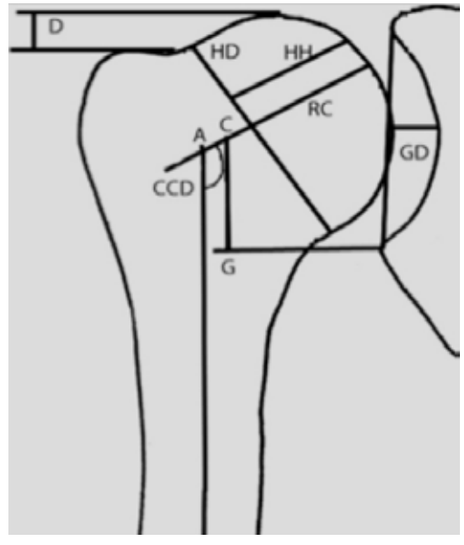

Figure 1

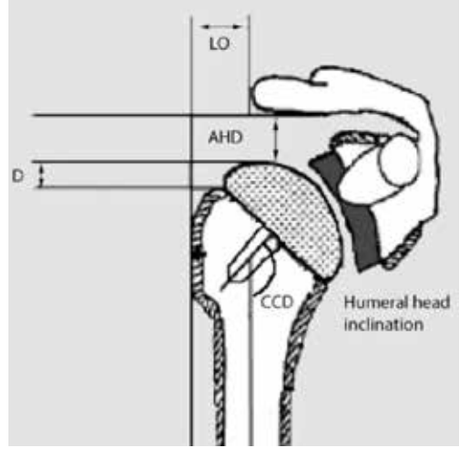

Figure 2

RESULTS

Follow-up

All patients were reviewed clinically and radiographically at an average of 5 years follow-up (2-10).

Clinical results

At the last follow-up, the Constant score reached 64 points or 82% with 132° of anterior elevation, 32° of external rotation, and 2,7 points of internal rotation. Results were satisfactory in 75% of the cases according to the Neer score. Better results were observed for primary osteoarthritis whereas less favorable results were noted for rheumatoid arthritis.

	Preop	Last follow-up
Pain (VAS)	6.8 pts	2.7 pts
Active anterior elevation	108°	132°
External rotation	10°	32°
Internal rotation	3.8 pts	6.5 pts
Absolute Constant score	33.6 pts	64.3 pts
Ponderated Constant score	42%	82%

Table 1
Clinical results

Radiographic results

Immediately postoperatively, radiographic analysis found implants smaller than the native humeral head, mostly in varus with an increase lateralization. With follow-up, we observed proximal migration of the humerus, and decrease lateralization, secondary to glenoid wear and rotator cuff thickening. At follow-up, there was no lucent line and no loosening in the series. There was no correlation between implant positioning and glenoid wear, complication rate, or revision rate. (Figure 2)

	Preop/Postop	Stats	Postop/last F/u	Stats
HD	-1.8	P<0.01	-	-
HH	-2.1	P<0.001	0	Ns
RC	+0.8	Ns	+2.6	P<0.001
PM	+0.8	Ns	-2.5	P<0.001
AHD	0	Ns	-2	Ns
CCD	-7	P<0.001	+1	Ns
LO	+4.4	P<0.001	-1.2	P=0.028
GD	+0.4	P=0.009	+1.5	P<0.001

Table 2
Radiographic results Complications

Complications

At last follow-up, there were 33 complications, 27 of which concerned symptomatic glenoid wear and 3 cuff lesions. The mean time before symptomatic glenoid wear was 4,6 years and a revision procedure was necessary in 14 cases. There was no correlation between type of preoperative and postoperative glenoid wear, between etiology and radiographic glenoid wear, and between etiology and symptomatic glenoid wear. The survival rate without complication was 28.7% à 8 years.

Revisions

There were 15 revisions procedures. For the 14 revisions for symptomatic glenoid wear different procedures were performed: 6 totalization, 2 total anatomical stemmed arthroplasty, 4 total reversed arthroplasty, 1 pyrocarbon spacer and 1 articular debridement with biceps tenotomy. The survival rate without revision was 59% à 8 years. Finally, there was no correlation between etiology and revision.

DISCUSSION

Copeland originally developed resurfacing implants, applied in degenerative shoulder pathology as whole[1, 2, 9-11, 15]. The aim was to reproduce humeral head anatomy to compensate for humeral head wear, to restore optimal rotator cuff function while conserving humeral bone stock. Radiographic analysis showed that the Copeland resurfacing implant provided 6-mm postoperative lateral offset, compensating for osteoarthritis-related wear[6].

Several studies have reported the difficulty to position adequately a resurfacing prosthesis. Most prostheses are positioned with excessive anteversion[4], in varus[12], with a non-adapted implant size[19]. Reaming depth is difficult to appreciate, and insufficient depth will induce a tendency to excessive lateral offset of the humeral head.

The literature reports satisfactory results with resurfacing implants for primary osteoarthritis of the shoulder [9-12, 15, 17, 21]. Over time, however, progressive glenoid wear occurs[12]. Thomas et al[21] also reported reduced lateral offset over time, indicating progressive glenoid wear; other studies reported similar evolution implicating excessive humeral head size and stress to the glenoid surface[1, 2, 8, 13, 14, 17].

Resurfacing shoulder arthroplasty thus does not seem to resolve the problem of long-term glenoid wear encountered in hemiarthroplasty, which occur earlier when resurfacing implant size and positioning are not well-adapted[7]. A glenoid implant seems to be the best option to decrease pain level and ensure recovery of functional motion[16].

This study has some limitations. However, since this experience we modified our practice. We stopped using resurfacing as hemiarthroplasty; from 2010 to 2013, we have used resurfacing with a glenoid component with so far very satisfactory results; however, since 2013 we used convertible short stem prosthesis as hemi or total arthroplasty.

CONCLUSION

Functional results of resurfacing shoulder arthroplasty deteriorated with follow-up with only 75% satisfactory results at 5 years. Main concerns are related to recurrence of pain related to glenoid wear necessitating in most of the cases a revision procedure. Resurfacing implants must be abandoned and other therapeutic option must be chosen.

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22/ PYROCARBON INTERPOSITION SHOULDER ARTHROPLASTY: PRELIMINARY RESULTS FROM A PROSPECTIVE MULTICENTER STUDY AT 2 YEARS OF FOLLOW-UP

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INTRODUCTION

The first interposition arthroplasty was performed in 1889 by Ollier[34] using fascia lata to treat wrist arthropathy. More than a century later, the concept of interposition arthroplasty was reintroduced using silicone implants, yielding satisfactory clinical results but generating considerable debris and subsequent failures.[27,32,47] Nowadays, the use of pyrolytic carbon (pyrocarbon) contributes to the concept of free interposition arthroplasty, with excellent midterm and long-term outcomes, notably relief of pain and functional recovery.[1,5,20,36,39] Pyrocarbon is a highly biocompatible material that has been used for heart valves since the 1970s[8,9,22,23] and for hand and wrist arthroplasty since the 1990s.[4,13,15,37] The coherent findings of different authors suggest that pyrocarbon is a durable implant material that generates little or no wear[19,20] and therefore provides longevity.[19,35]

Various shoulder arthroplasty systems exist for the treatment of degenerative glenohumeral joints. Total shoulder arthroplasty (TSA) is used for patients with intact rotator cuffs, and reverse shoulder arthroplasty (RSA) is preferred in patients with deficient rotator cuffs or glenoid deficits.[48] Hemishoulder arthroplasty (HSA) is primarily used in patients with healthy glenoid cartilage[26,41,44,49] or to avoid frequent glenoid complications and revisions observed after TSA in younger patients.[17] Recent comparative studies demonstrate, however, that TSA offers better clinical outcomes than HSA.[26,38,40,42] The reason for this discrepancy is believed to be erosion or damage of glenoid bone by hard metallic prosthetic heads.[30,42]. To address this issue, a pyrocarbon interposition shoulder arthroplasty (PISA) implant, designed to be freely positioned in a reamed cavity within the proximal humerus, was designed to replace metal articular surfaces by pyrocarboncoated graphite. Pyrocarbon has superior tribologic properties than metal because it can slide against bone and cartilage without causing pain or damage.[7,12] The present study reportsthe clinical and radiographic outcomes of this new PISA, implanted for osteoarthritis (OA), at a minimum follow-up of 2 years. The hypotheses were that the implant would (1) grant improvement of pain and function equivalent to those reported for TSA and (2) would cause little or no detectable erosion to the glenoid articular surface.

MATERIALS AND METHODS

Study design

The study prospectively included 67 consecutive patients who underwent shoulder interposition arthroplasty using the Inspyre implant (Tornier SAS, Montbonnot Saint Martin, France) at 9 centers between March 2010 and October 2012. The implant consists of a graphite sphere coated with pyrocarbon, which is freely positioned in a reamed cavity within the proximal humerus, articulating directly against the glenoid. The main criteria for the use of the Inspyre implant were similar to the indications for HSA with preservation of glenoid bone stock, notably young age or high activity level, or both. All patients were informed of the innovative nature of this implant and provided their consent to participate in the study.

The initial cohort included 33 women (49%) and 34 men (51%) aged 50.7 ± 11.4 years (median, 52; range, 18-77 years; Fig. 1).

Surgery was performed on 45 right shoulders (67%), with no bilateral patients, and 45 cases (67%) involved the dominant side. The indications included 42 shoulders (63%) with primary OA, 13 (19%) with avascular necrosis (AVN), and 12 (18%) with secondary OA postinstability or postfracture. The activity level was strenuous in 10 patients (15%), moderate in 46 (69%), and inactive or sedentary in 11 (16%). Previous operations had been performed on 27 (40%) shoulders: 8 for instability, 7 open reductions with internal fixation for proximal humeral fractures, 6 subacromial decompressions, 3 tenotomies of long head

of biceps, 2 rotator cuff repairs, and 12 other procedures (some shoulders had more than 1 procedure).

Preoperative assessments

Preoperative clinical assessment was completed using the absolute Constant score. Radiologic assessments were performed by a central observer (J.G.) on frontal anteroposterior x-ray views (external, neutral, and internal rotations) and supraspinatus outlet views. Magnetic resonance imaging or computed tomography scan images were used to evaluate the native glenoid morphology according to the Walch classification.

Surgical technique

All patients were operated on under general anesthesia in the beach chair position. The deltopectoral approach was used in 66 shoulders (98.5%), with tenotomy or peeling of the subscapularis from the lesser tuberosity, followed by its reinsertion using transosseous sutures. Tenotomy and tenodesis of the long head of biceps were performed in 54 shoulders (81%) and anterior juxtaglenoid capsulotomy to release internal rotation contracture in 27 shoulders (40%). The glenoid surface was not reamed in any of the shoulders.

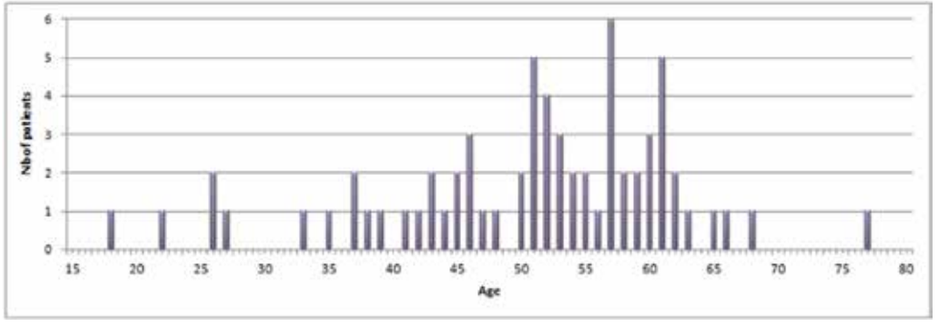

Figure 1
Distribution of the 67 included patients by age: 5 were younger than 30 years, 6 were in their 30s, 12 in their 40, 29 in their 50, 14 in their 60s, and only 1 was older than 70. Mean age was 50.7 ± 11.4 years, and median was 52 years

Humeral head resection was performed at the anatomic neck level, and the measured dimensions of the resected bone were 46.5 ± 4.9 mm superoinferiorly, 43.1 ± 4.7 mm anteroposteriorly, and thickness was 14.5 ± 3.7 mm.Acavity was then reamed in the center of the humeral metaphysis using hand-operated compactors and motorized reamers, leaving a 2-mm-thick peripheral bony rim at the equator. To maintain adequate tension within the rotator cuff, the depth of the bone cavity was adjusted to correct lateral offset, which was slightly increased in most cases. Consequently, an intentional slight overstuffing can be observed on postoperative x-rays. The target offset, once the Inspyre implant is inserted, is slightly greater than the anatomic offset. This is because the implant diameter is 4 mm smaller than the native humeral head, compensating for the 2-mmthick peripheral bony rim. The diameters of implants used were in the range of 34 to 46 mm.

The diaphyseal canal orifice and the metaphyseal cavity were both filled with impacted bone graft taken from the humeral head in 46 shoulders (69%). Trial reduction allowed verification of range of motion and rotator cuff tension, particularly of the subscapularis, as well as good soft tissue balancing, responsible for anteroposterior stability of the implant. Potential impingement zones were identified, particularly between the inferior margin of the humeral head and the glenoid socket. Humeral bone resections were made if necessary. There was 1 intraoperative complication (a greater tuberosity fracture without displacement that consolidated spontaneously during immediate postoperative shoulder immobilization before rehabilitation started) and 1 immediate postoperative complication (hematoma).

Postoperative rehabilitation

All patients followed the standard rehabilitation protocol after HSA for each center. The shoulder was immobilized for 4 weeks: 40 patients wore a simple sling, 6 wore an abduction splint, and 9 wore a neutral rotation brace.

Postoperative assessment

Postoperative clinical assessment using the absolute Constant score was completed at a minimum follow-up of 2 years by the surgeons who performed the operation. Radiographic assessment was performed by 1 central observer (J.G.), comparing preoperative, immediate postoperative, and 2-year frontal x-ray images in external, neutral, and internal rotation as well as a supraspinatus outlet views.

All x-ray assessments and measurements were performed on comparable anteroposterior views. The central observer noted the evolution of 5 radiographic criteria over time: glenoid erosion, tuberosities thinning, subacromial space reduction, implant subsidence, and humeral medialization (Fig. 2).

For the evolution of medialization, the reference was the preoperative value. For all other criteria, to avoid magnification errors, measurements were calculated relative to the implant diameter. The 2-year follow-up x-rays were compared with the earliest available x-rays (maximum 6 months postoperative) to assess evolution of the radiologic criteria.

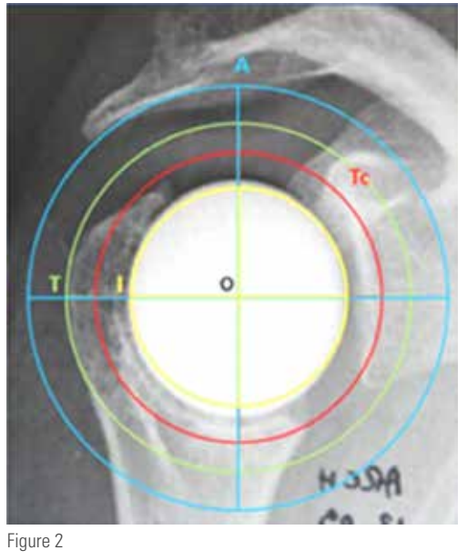

Figure 2
Evaluation of radiologic criteria: glenoid erosion (OTc/ OI), tuberosities thinning (OT/OI), and subacromial space (OA/OI).

Statistical analysis

Quantitative and descriptive statistical analyses were performed depending on whether variables were continuous or discrete. This was an explorative study; therefore, a priori sample size calculation was not performed because there was no established control group.

Figure 1 Distribution of the 67 included patients by age: 5 were younger than 30 years, 6 were in their 30s, 12 in their 40, 29 in their 50, 14 in their 60s, and only 1 was older than 70. Mean age was 50.7 ± 11.4 years, and median was 52 years.

Figure 2 Evaluation of radiologic criteria: glenoid erosion (OTc/ OI), tuberosities thinning (OT/OI), and subacromial space (OA/OI). Pyrocarbon interposition shoulder arthroplasty 3

Clinical quantitative parameters were submitted to analysis of variance using a repeated-measurement model considering time, age, and gender as fixed effects and subject as random effect. Comparisons between different follow-up visits were performed from the mixed linear model using an adjustment method. The effect of 5 demographic criteria (gender, age, etiology, level of activity, and device diameter) on the evolution of 2 radiographic criteria (glenoid erosion and tuberosities thinning) at the earliest and the latest followup visits were analyzed using the generalized estimating equations model. P values of <.05 were considered statistically significant. Survival analysis was performed using the Kaplan-Meier method.

RESULTS

From the 67 patients enrolled, 7 underwent revision surgery, 2 were lost to follow-up, and 3 had their original implant in place but did not complete outcome assessments. The remaining 55 patients, aged 49.3 ± 12.0 years (median, 51; range, 18 to 77 years), were evaluated clinically and radiographically. They included 2 patients who underwent reoperations without implant removal.

Complications and revisions

Complications were analyzed, and 5 groups of causes for revision or reoperation were identified:

1. Aggravation of pre-existent posterior subluxation in 2 patients (1 B1 glenoid revised to TSA at 8 months, and 1 B2 glenoid revised to a larger diameter implant at 16 months);
2. Inferior glenohumeral impingement causing pain or stiffness, or both, in 2 patients (1 revised to TSA at 9 months, and the other underwent reoperation to remove the offending osteophyte);
3. Post-traumatic rotator cuff tears in 2 patients (revised to RSA at 11 and 18 months) without any thinning of tuberosities that could have weakened the rotator cuff; 4. Persistent glenoid pain in 1 patient (A1 glenoid with signs of hyperfixation on the single photon emission computed tomography scan, revised to TSA at 29 months); 5. Other causes in 2 patients (1 supraspinatus ossification treated by arthrolysis, and 1 painful shoulder with signs of bone damage and distal subsidence caused by an entrapped metal particle rubbing against the pyrocarbon sphere, revised to RSAat 26 months, showing wear zones on the retrieved implant).

There were no other cases of posterior subluxation nor any cases of shoulder instability reported at the last follow-up.

Clinical outcomes

Clinical evaluations were performed for 55 patients (30 women and 25 men) at a mean follow-up of 26.8 ± 3.4 months (median, 26; range, 24-38 months). The Constant score improved from 34.1 ± 15.1 points (median, 34.0; range, 8.0- 68.5 points) preoperatively to 66.1 ± 19.7 points (median, 72.5; range, 14.5-90.0 points) postoperatively (Table I).

The Constant score improved in all but 4 patients, with mean increase of 32.0 ± 21.1 points (median, 32.0; range –12 to 74.5 points). In patients who underwent operations for primary OA, the best scores were observed for type A glenoids. Outcomes for patients who underwent operations for secondary OA were good for post-Latarjet shoulders but poor for post-traumatic arthritis or sequelae of fracture. Scores for patients who underwent operations forAVN were good or excellent (Table II).

Radiographic outcomes

Glenoid erosion, tuberosities thinning, subacromial space reduction, implant subsidence, and medialization were assessed on the earliest (3-6 months) and the latest (29.8 ± 7.5 months; median, 28; range, 12-48 months) radiographic images available at the time of analysis. Progressive glenoid erosion was observed in 6 shoulders (Fig. 3), and tuberosity thinning was noted in 3 shoulders (Fig. 4). Some tuberosities were already quite thin after the operation but remained stable, with no reports or signs of fracture thereafter. Medialization of the humerus was observed in 9 shoulders, and decrease of subacromial space was noted in 4 shoulders. No bone loss and no revisions due to calcar resection were observed. The radiographic observations were not correlated with functional score, reported pain, or shoulder mobility. There were also no significant associations between glenoid erosion or tuberosities thinning and patient age, gender, indications (primary or secondary), level of activity, implant diameter, or Constant score or its pain component.

The radiographic analysis revealed also a humeral sclerotic bone densification line around the implant in 50 humeri (91%;

Table I Absolute Constant score preoperatively and at 2 years of follow-up*

Variable	Preoperative mean ± SD (min-max)	2-year FU mean ± SD (min-max)	Improvement mean ± SD (min-max)
Pain	4.0 ± 3.0 (0.0-14.5)	11.5 ± 3.6 (1.0-15.0)	7.5 ± 4.8 (–5.0 to 15.0)
Activities	6.8 ± 3.4 (2.0-15.0)	15.9 ± 4.3 (4.0-20.0)	9.1 ± 5.2 (–3.0 to 18.0)
Mobility	18.3 ± 8.5 4.0/16.0/40.0	30.6 ± 8.4 10.0/32.0/40.0	12.1 ± 11.2 –10.0/14.0/34.0
Strength	5.0 ± 5.1 (0.0-20.0)	8.8 ± 6.7 (0.0-24.0)	3.7 ± 6.3 (–7.0 to 24.0)
Total Constant score	34.1 ± 15.1 (8.0-68.5)	66.1 ± 19.7 (14.5-90.0)	32.0 ± 21.1 (–12.0 to 74.5)

FU, follow-up; *SD*, standard deviation.
* All Constant scores improvements are significant ($P < .0001$).

Table II Breakdown of Constant score for etiologies and glenoid types

Variable	No. (%) (N = 55)	Preoperative Mean ± SD	FU at 2 years Mean ± SD	Improvement Mean ± SD
Primary glenohumeral OA	32 (58)			
A1	17 (31.0)	35.0 ± 15.0	67.0 ± 20.0	33.0 ± 19.0*
A2	7 (13.0)	26.0 ± 13.0	73.0 ± 8.0	48.0 ± 14.0*
Total glenoid A	24 (44.0)	33.0 ± 15.0	68.0 ± 19.0	42.0 ± 7.0
B1	4 (7.0)	35.0 ± 12.0	61.0 ± 24.0	15.0 ± 30.0†
B2	3 (5.0)	44.0 ± 21.0	61.0 ± 29.0	17.0 ± 8.0‡
C	1 (2.0)	41.0	42.0	1.0‡
Total glenoid BC	8 (14.0)	38.0 ± 14.0	59.0 ± 23.0	14.0 ± 21.0
Osteonecrosis	12 (22)			
Medical	8 (14.5)	44.0 ± 14.0	77.0 ± 9.0	33.0 ± 13.0*
Traumatic	4 (7.5)	20.0 ± 19.0	64.0 ± 33.0	45.0 ± 35.0*
Total	12 (22.0)	36.0 ± 19.0	73.0 ± 20.0	37.0 ± 22.0
Secondary glenohumeral OA	11 (20)			
Post-Latarjet	6 (11.0)	35.0 ± 13.0	72.0 ± 16.0	37.0 ± 19.0*
Post-trauma	5 (9.0)	33.0 ± 14.0	51.0 ± 25.0	18.0 ± 16.0*
Total	11 (20.0)	34.0 ± 13.0	62.0 ± 22.0	28.0 ± 19.0

FU, follow-up; *OA*, osteoarthritis; *SD*, standard deviation.
* Significant improvement ($P < .0001$).
† Not significant: 2 patients showed a total Constant score improvement of 50 and 32 points respectively and 2 patients showed a total Constant score decrease of 8.5 and 12 points.
‡ Not significant: too small number of patients.

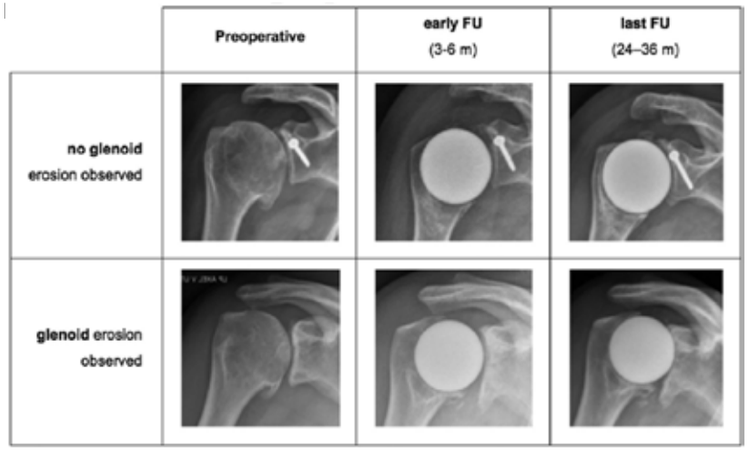

Figure 3
Progressive glenoid erosion was observed in 6 shoulders. FU, follow-up.

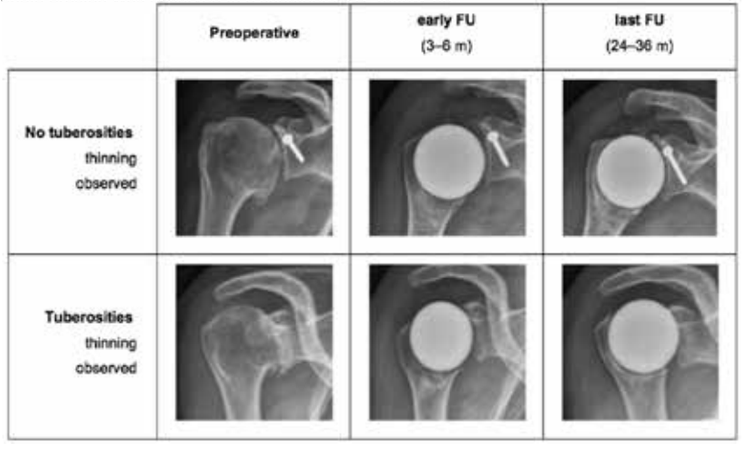

Figure 4
Tuberosity thinning was noted in 3 shoulders. FU, follow-up.

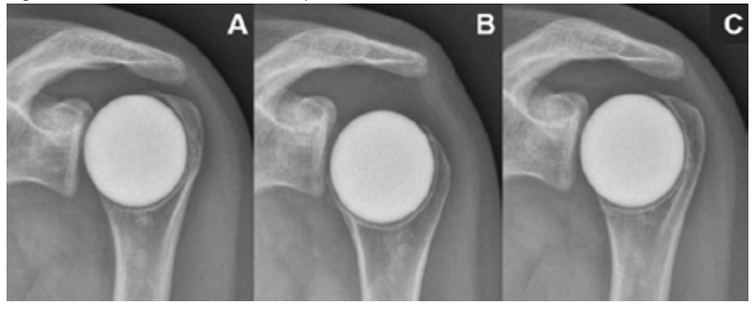

Figure 5
Anteroposterior x-rays views in (A) external, (B) internal, and (C) neutral rotation of the same shoulder show sclerotic bone densification line forming around the implant on the humeral side. Note the voluntary calcar resection to avoid inferior glenohumeral impingement.

Implant survival

Implant survival was estimated at a mean follow-up of 49.7 ± 7.3 months (median, 48.5 range 35.9-64.4 months), accounting for information collected by the sponsor surveillance register, allowing us to obtain permanently updated safety data concerning all implanted Inspyre devices. This explains the difference of follow-up intervals between the survival and clinical outcomes analyses. The end point for revision was defined as removal of the implant for any reason. The revision incidence was 10.8% (7 of 65), and the Kaplan-Meier survival was 89.2% (95% confidence interval, 81.8%-96.7%) at a mean follow-up of 49.7 ± 7.3 months (Fig. 6).

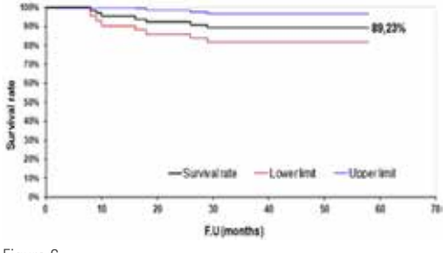

Figure 6
Kaplan-Meier survival with end point being implant revision for any reason. FU, follow-up.

DISCUSSION

The findings of the present study reveal uncertainties about the short-term clinical outcomes of PISA. The clinical scores and implant survival of the present series were better than or comparable to those of HSA but are inferior to those reported for TSA. The radiographic findings revealed some patients with glenoid erosion and thinning of humeral tuberosities, but longer-term assessment is needed to confirm whether this was caused by progressive bone loss or by bone remodeling. We have therefore decided to use shoulder interposition arthroplasty with greater caution and in restricted indications while awaiting longer-term outcomes to confirm the safety and efficacy of this concept.

The postoperative Constant score for the present series was 66.1 at a mean follow-up of 2.2 years. In a meta-analysis of 20 articles on TSA (1576 shoulders), Carter et al10 found the mean postoperative Constant score was 69.8 at 3.7 years. The literature demonstrates that Constant scores are generally inferior after HSA compared with TSA. In a recent comparative study, Sandow et al40 reported Constant scores of 54.5 for HSA compared with 77.0 for TSA. Other comparative studies reported less disparate results for HSA and TSA: 65.8 vs. 67.8,21 and 61.2 vs. 68.6,38 respectively. The mean score of the present series is lower than typical scores after TSA, but slightly higher than scores after HSA.

The revision rate for the present series was 10.4% at a mean follow-up of 4.1 years. In a recent systematic review, van den Bekerom et al[46] reported revision rates of 13% for HSA compared with 7% for TSA at a minimum follow-up of 7 years.

In a comparative study, Bartelt et al[2] reported revision rates at 5 and 10 years, respectively, of 15% and 28% for HSAvs. 0% and 8% for TSA. The cohort study with longest followup of HSA is that of Levine et al[29] who reported a revision rate of 29% at 17.4 years. Strauss et al[43] studied the benefits of adjuvant biologic resurfacing of the glenoid with HSA and reported extremely high revision rates of 51% at 3.4 years.

The revision rates of the present series should not be directly compared with those reported in the recent literature because of the substantial variations in follow-up periods and because of differences in indications for surgery and causes of revision. However, the rates of complications and revisions observed in our series with an average follow-up of 49.7 months are relatively high and brought us to reduce implanting this new device on a regular basis.

The use of shoulder arthroplasty has widened progressively in recent decades to younger patients with greater functional demands and rotator cuff tears. Dillon et al[16] investigated the effect of age on implant survival and reported an incidence of rotator cuff tears of 5.4% in younger patients (<59 years) compared with 2.5% in older patients (>59 years). In young patients with healthy glenoid cartilage,[26,41,44,49] partial arthroplasty, or HSA, is theoretically preferable, because the glenoid bone stock is preserved along with the joint capsule and labrum. Such implants prevent risks of glenoid component loosening and simplify the surgical technique, particularly in case of revision to TSA.[6,11,14,18,28,31,45] The question whether the greater revision rates for HSA or interposition arthroplasty are counterbalanced by benefits to patients of bone preservation and simpler future revisions remains controversial.[21,46] Patients in the present series were a mean age of 49 years at the index operation, which could be associated with greater patient expectation and functional demands.[25] The systematic review of van den Bekerom et al[46] suggested that the mean age is approximately 55 years for those undergoing HAS and approximately 64 years for those undergoing TSA.

To our knowledge, this is the first report of outcomes of shoulder interposition arthroplasty and performance of pyrolytic carbon in the shoulder joint. The Inspyre implant design is based on (1) the absence of fixation to bone that grants mobility, (2) the integrity of rotator cuff tendons and adequate filling of joint space to provide sufficient stability and leverarms, and (3) the creation of articular surfaces at the bonepyrocarbon and cartilage-pyrocarbon interfaces. As demonstrated in previous investigations, pyrocarbon-coated implants provide excellent outcomes in the hand and wrist[3,13,15,24,37] because the material induces little or no wear.[19,20]

The radiographic findings of the present series showed evidence of sclerotic bone densification in most humeri, which indicates bone adaptation around the implant. The glenoid erosion and thinning of humeral tuberosities observed in some patients could be due to progressive bone loss or bone remodeling.

Only long-term assessment could explain these phenomena with certainty and therefore reveal whether humeral bone loss could be exacerbated at later follow-up and potentially compromise the ease and outcomes of revision arthroplasty.

To our knowledge, only 1 published study has quantified radiographic changes in glenoid depth and joint space after HSA33 and observed progressive glenoid erosion in most shoulders.

In agreement with our findings, the authors found no correlations between severity of glenoid erosion and clinical results.

Our preliminary clinical outcomes enabled identification of the most suitable indications for PISA: (1) primary OA with concentric glenoid deformity (type A glenoids), (2) postinstability OA, and (3) humeral head AVN (Fig. 7).

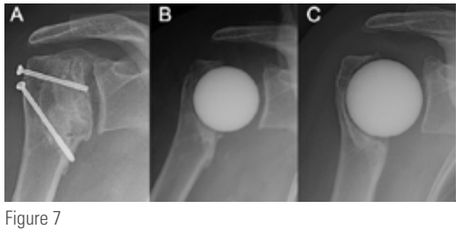

Figure 7
Example of a favorable indication. (A) Preoperative, (B) immediate postoperative, and (C) 4-year postoperative shoulder x-rays of a 40 year-old patient who suffered post-traumatic avascular necrosis with severe collapse of the humeral head, responsible for a painful stiffness. Clinical outcomes (Constant score, 81) and radiologic evolution are excellent and stable without any glenoid status evolution.

However, the outcomes for patients with posterior wear (type B or C glenoids) were considerably lower than expected, with worsening of the posterior translation in some patients and possible glenohumeral impingement, and are definitely not a good indication for the Inspyre interposition arthroplasty.

It is important to note that the diameter of the Inspyre implant is approximately 4 mm smaller than that of the native humeral head. The resulting clearance could be responsible for posterior humeral translation or subluxations in type B or C glenoids. The discrepancy between native and prosthetic articular diameters could also be responsible for glenoid erosion and reduced mobility.

This study has several limitations, mainly related to its short clinical follow-up, the variety of indications for surgery, and the lack of a control group that would have enabled more direct comparisons of outcomes. The decision to perform a noncontrolled study was motivated by the specific and rare indications for PISA, including young age of the patients, which render it unsatisfactory to implant TSA in these patients and inappropriate to implant HSA considering the published shortcomings of a metallic articular surface against the native glenoid. Furthermore, the multicenter nature of this study and the learning curve required for its implant design were not accounted for in the analysis of the results. The latter could explain the relatively high revision rate and some of the outliers in terms of clinical scores.

This study has several strengths, however, because it is a prospective continuous series on a sizeable cohort. It is the first to report outcomes of shoulder interposition arthroplasty and the first to present performance of pyrolytic carbon for direct articulation against bone and cartilage in the shoulder joint.

CONCLUSION

The short-term findings of this prospective continuous series reveal uncertainties about the clinical outcomes of PISA. The study enabled identification of contraindications and potential causes of failure, which were related to the concept of free interposition and smaller radius of curvature of the sphere.

The radiographic outcomes suggest that pyrocarbon is a suitable articular material because it induces minimal bone and cartilage wear. Longer-term follow-up is necessary to confirm the durability of biomechanics and safety for this implant as well as its optimal indications.

Acknowledgments

The authors thank Dr. Solange Van de Moortele for her valuable help in coordinating the study and Mo Saffarini for his assistance with reviewing and editing of the manuscript.

Disclaimer

This study was sponsored by Tornier SAS (Montbonnot, France). Jérôme Garret, Arnaud Godeneche, Mikael Etzner, Luc Favard, Christophe Levigne, François Sirveaux, Marc- Olivier Gauci, Charles Dezaly, and GillesWalch received fees for their participation in collecting and analyzing data.

The the other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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23/ PYROCARBON HUMERAL HEAD IN HEMI SHOULDER ARTHROPLASTY: PRELIMINARY RESULTS AT 2-YEAR FOLLOW-UP

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INTRODUCTION

Anatomical shoulder replacement can be performed as a total shoulder arthroplasty (TSA) or a hemi shoulder arthroplasty (HSA), depending on the native glenoid status. When the glenoid cartilage is intact, such as in osteonecrosis or humeral fracture, HSA may be a good option. When the glenoid cartilage is damaged, TSA is often preferred but it introduces the risk of glenoid component complications [5, 6, 25]. For this reason, HSA can still be considered as a viable solution for young patients despite the risk of postoperative pain and glenoid erosion - presumably caused by the friction of the metallic humeral head against the glenoid bone [14, 21].
Thanks to its unique tribologic and elastic characteristics, as well as its surface properties, pyrocarbon is expected to overcome the limitations of conventional HSA with metallic head. The first clinical use of pyrocarbon was in heart valves in the 1970s. Since the 1980s, pyrocarbon has demonstrated excellent biocompatibility and safety in orthopedic applications. Numerous papers have reported satisfactory results when used for hand and wrist arthroplasty and it has proven to be a durable material, producing little or no wear, and therefore granting implant longevity [4, 10, 18]. Consequently, this material properties might help preventing erosion of the glenoid surface and reducing the associated pain [3, 11, 19].
The goal of the present study was to report clinical and radiological outcomes, at a 2-year minimum follow-up, of HSA using a new pyrocarbon humeral head, in various etiologies affecting young patients.

MATERIALS AND METHODS

Study design

The authors prospectively included 65 consecutive patients that underwent HSA with a Pyrocarbon Humeral Head (Tornier SAS, Montbonnot, France), performed by 5 surgeons in 5 different centers from 3 countries between July 2013 and April 2015. All patients, aged over 18-year old, with a functional rotator cuff and presenting an indication for HSA were included, no exclusion criteria were applied.
The implant consists of a graphite core coated with a pyrocarbon bearing surface and fixed on a double male CoCr taper, designed to be assembled onto an Aequalis™ Ascend™ Flex convertible humeral stem (Tornier SAS, Montbonnot, France) (Fig. 1).

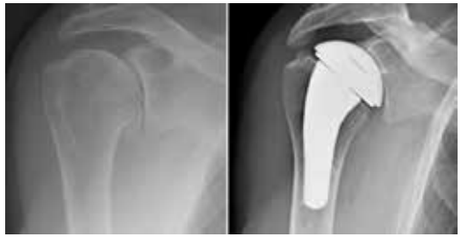

Figure 1
Example of a shoulder implanted with a humeral stem assembled with a pyrocarbon humeral head (left: baseline – right: 2-year follow-up)

The humeral heads were available in 6 sizes from 39x14 to 50x16mm, each of them offered with 2 different eccentricities (low 1.5mm and high 3.5/4mm) to restore the posterior and medial offset [1]. Prior to any inclusion, approvals of Ethical Committees were obtained as required by local regulations and informed consent was obtained from all individuals participants included in the study.

Clinical and radiological assessments

Preoperative and postoperative clinical assessments were performed using the Constant' score. Patient satisfaction was measured with the Single Assessment Numeric Evaluation (SANE) score. Radiological assessments were performed on the series of 58 patients having images available both at baseline and at follow-up. Evaluations were systematically performed on axillary and antero-posterior x-ray views (external, neutral and internal rotations). Preoperative MRI or CT scan images were used to evaluate the glenoid morphology according to the Walch classification [27]. All images were reviewed by 1 central observer (J.G.). Glenoid erosion was evaluated subjectively on a 4 levels scale as "none / mild / moderate / severe", as described by Sperling [26] and illustrated in Figure 2.

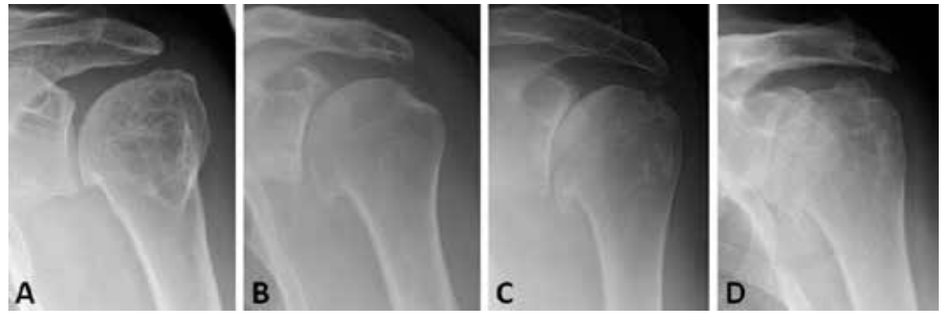

Figure 2
Illustration of the 4 levels scale for glenoid erosion assessment (A = none, B = mild, C = moderate, D = severe)

Surgical technique

The deltopectoral approach was used in all shoulders, with tenotomy of the subscapularis from the lesser tuberosity, followed by its reinsertion using trans-osseous and/or tendon-to-tendon sutures. Tenotomy or tenodesis of the long head of biceps was performed when needed. The labrum and capsule were preserved to maintain stability and proprioception. Resection of the coraco-humeral ligament and/or juxta-glenoid capsulotomy were performed in 9 shoulders with stiffness in external rotation.

Postoperative rehabilitation

All patients followed the same standard rehabilitation protocol as for conventional anatomical prosthesis, with shoulder immobilization for up to 6 weeks. Rehabilitation and physiotherapy were prescribed, consisting in passive automobilization in anterior elevation without external rotation to preserve the subscapularis repair. For OA patients presenting a B glenoid with posterior subluxation, shoulders were immobilized in neutral rotation, with no immediate mobilization in internal rotation.

RESULTS

From the 65 patients enrolled, 1 was lost to follow-up and 3 underwent revision surgery before their 2-year follow-up. 61 patients, 20 women (33%) and 41 men (67%), mean age 57.9±13.3 years (median 58; range 19–84) at index surgery, were evaluated clinically and radiographically at a mean follow-up of 25.9±3.3 months. Indications, along with glenoid types according to Walch's classification [27] included: 37 shoulders with primary OA (21 type A glenoids, 16 type B glenoids), 11 with osteonecrosis (7 atraumatic, 4 post-traumatic), 11 with secondary OA (7 post-instability, 4 post-traumatic) and 2 with rheumatoid arthritis (RA) (Table 1).

		Baseline visit		2-year FU visit		Improvement (individual changes)	
Indications	**N**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
1. Primary OA							
A1	14	**32.2**	13.7	**79.7**	12.6	**47.5**	14.9
A2	7	**34.7**	15.3	**80.0**	9.1	**45.3**	10.5
B1	10	**31.9**	19.9	**78.8**	14.4	**46.9**	21.2
B2	6	**33.8**	16.9	**77.7**	10.0	**44.0**	16.0
2. Secondary OA							
Post-Traumatic	4	**16.9**	10.8	**37.5**	21.6	**20.6**	18.5
Post-Instability	7	**30.2**	17.9	**80.9**	8.5	**50.7**	19.3
3. Osteonecrosis							
Post-Traumatic	4	**25.8**	16.0	**55.5**	24.1	**29.7**	16.0
Atraumatic	7	**36.6**	16.9	**79.5**	9.8	**48.1**	16.5
4. RA							
	2	**20.9**	4.4	**69.8**	7.1	**48.9**	2.7
Total	**61**	**31.0**	15.8	**74.8**	17.0	**44.4**	17.5

Table 1
Breakdown of total Constant score by indications and glenoid types

Surgery was performed on 27 (44%) dominant side shoulders. Previous surgeries had been performed on 22 shoulders: 9 osteosyntheses for fracture, 6 instability surgeries, 1 glenoid bone graft to compensate a bone defect, 1 cuff repair, 1 acromioplasty, 1 coracoplasty, 1 synovectomy, 1 axillary dissection, 1 cartilage and labrum smoothing.
1 per-operative humeral shaft fracture occurred and was repaired with an osteosynthesis plate without sequelae.

Revisions and implant Survival

From the initial cohort, 3 patients, all with primary OA (2 A and 1 B2 glenoids), underwent revision surgery. For one patient, the cuff was suspected to be weak since, 1 year after surgery, a superior migration of the humeral head was observed with a progressive functional degradation associated with pain and active mobility impairment. This patient was successfully revised at 16-month post-surgery. The pyrocarbon head was explanted, the stem was preserved and easily converted from anatomic to reverse configuration. The 2 other patients were both revised for postoperative glenoid bone pain persistent at 16 months after surgery. One patient with primary OA and a B2 glenoid was easily and successfully revised to RSA, thanks to the convertibility of the stem. The other patient was revised by a surgeon not participating in the study. We learned that the pyrocarbon humeral head was exchanged for a metallic one. The patient condition has not improved and the outcomes are still poor. No other postoperative complications were reported. Considering all humeral head removals (n=3), whatever the reason, the survival rate was 95.3% at 2-year follow-up.

Clinical outcomes

The mean total Constant's score for the series of 61 patients improved from 31.0±15.8 preoperatively to 74.8±17.0 postoperatively (Table 1), with a mean increase of 44.4±17.5 points. Pain and Activity Constant sub-scores improved by 9.8±3.1 and 16.7±3.9 points respectively (Table 2).

		Constant PAIN score						Constant ACTIVITY score					
		Baseline visit		2-year FU visit		Improvement (individual changes)		Baseline visit		2-year FU visit		Improvement (individual changes)	
Indications	N	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1. Primary OA													
A1	14	**3.6**	2.1	**13.9**	2.2	**10.3**	2.8	**6.2**	3.0	**18.1**	3.6	**11.9**	3.4
A2	7	**4.3**	2.7	**14.6**	1.1	**10.3**	3.0	**8.0**	3.4	**18.7**	1.8	**10.7**	3.6
B1	10	**3.6**	2.2	**13.2**	3.0	**9.6**	3.2	**6.9**	2.9	**15.0**	4.2	**8.1**	3.9
B2	6	**2.7**	1.8	**12.5**	2.4	**9.8**	2.7	**7.0**	1.8	**17.0**	1.8	**10.0**	2.3
2. Secondary OA													
Post-Traumatic	4	**2.0**	0.8	**9.8**	5.6	**7.8**	5.3	**3.5**	2.6	**12.5**	4.4	**9.0**	5.4
Post-Instability	7	**2.7**	2.3	**13.7**	1.6	**11.0**	3.4	**4.9**	1.9	**18.0**	2.5	**13.1**	2.8
3. Osteonecrosis													
Post-Traumatic	4	**4.0**	3.8	**12.0**	1.2	**8.0**	3.7	**6.8**	3.0	**11.3**	6.8	**4.5**	6.5
Atraumatic	7	**3.5**	2.1	**13.4**	2.1	**10.4**	2.5	**6.8**	1.8	**18.1**	1.2	**11.7**	1.9
4. RA													
	2	**3.5**	3.5	**9.5**	3.5	**6.0**	0.0	**8.0**	2.8	**16.5**	2.1	**8.5**	0.7
Total	**61**	**3.4**	2.2	**13.1**	2.7	**9.8**	3.1	**6.4**	2.8	**16.7**	3.9	**10.3**	4.1

Table 2
Breakdown of Constant Pain and Activity sub-scores by indications and glenoid types

In this series, all etiologies subgroups, except traumatic sequelae, reported good results, with a minimum mean improvement of the Constant' score of 44.0±16.0 points (Primary OA with B2 glenoids), and up to 50.7±19.3 points (Secondary OA post-instability). Conversely, results for patients presenting traumatic sequelae (secondary OA or osteonecrosis) were rather poor, with a mean improvement of 20.6±18.5 and 29.7±16.0 respectively.

Patient satisfaction

The mean SANE score for the whole series improved from 32% preoperatively to 78% postoperatively (Table 3). Patients with primary OA and B2 glenoid were among the most satisfied patients. Patients with primary OA and A glenoid, secondary OA post-instability or atraumatic osteonecrosis, reported a 50% or greater increase of SANE after surgery. Patient with RA or secondary post-traumatic OA or post-traumatic ON reported a low improvement in SANE (less than 35%).

	Baseline visit			2-year FU visit		
Indications	N	Mean (%)	SD	N	Mean (%)	SD
1. Primary OA						
A1	12	**36**	12	13	**88**	16
A2	6	**38**	26	7	**86**	13
B1	9	**36**	9	10	**77**	16
B2	4	**23**	19	6	**82**	10
2. Secondary OA						
Post-Traumatic	3	**27**	25	4	**54**	36
Post-Instability	7	**28**	13	7	**86**	9
3. Osteonecrosis						
Post-Traumatic	2	**18**	4	4	**46**	30
Atraumatic	4	**29**	30	7	**78**	24
4. RA						
	2	**38**	4	2	**68**	11
Total	**49**	**32**	**17**	**60**	**78**	**21**

Table 3
Breakdown of SANE score for indications and glenoid types

Radiographic Outcomes

Before surgery, in the 58 evaluated patients, 16 glenoids were described as having no erosion, 17 with mild erosion, 13 with moderate erosion and 12 with severe erosion. At 2-year follow-up, 50 (86%) glenoids showed no progression of erosion as compared to their preoperative status and the erosion evolved slightly (i.e. evolution of no more than 1 level of the 4 levels scale of erosion as described in M&M) in 8 (14%) glenoids. In some patients presenting a B glenoid preoperatively, a centering of the humeral head in front of a seemingly remodeled glenoid socket could be observed on postoperative CT-scans (Figure 3).

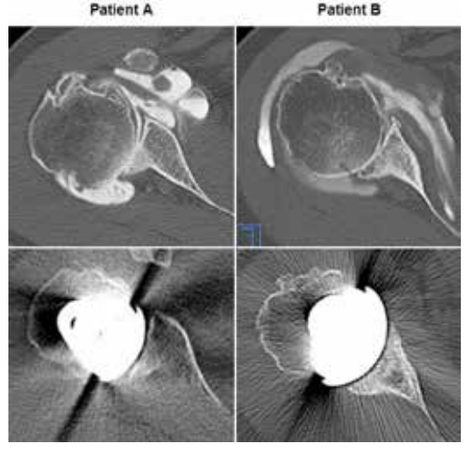

Figure 3
Examples of CT scan images from 2 patients with B1 type glenoids at baseline (upper images: baseline – lower images: 4-year follow-up)
A re-centering effect of the humeral head can be observed on the postoperative images

DISCUSSION

The findings of the present study provide encouraging results for pyrocarbon HSA. The mean postoperative total Constant' score for our whole series was 74.8±17.0 points at a mean follow-up of 25.9±3.3 months and no major postoperative glenoid erosion was observed. These results will be discussed according to each etiology as outcomes vary greatly from one to another and as it will help identifying indications for which pyrocarbon HSA shows the most promising results.

Atraumatic osteonecrosis has already been reported to be a good indication for HSA [7, 22] particularly in young patients with preserved glenoid cartilage [6]. As expected, in our series, the results obtained for this indication were satisfactory, with a mean postoperative Constant score of 79.5±9.8 points and an improvement of 48 points as compared to baseline. Conversely, outcomes for post-traumatic osteonecrosis, even without malunion of the tuberosities or cuff tear, were rather poor, confirming results reported from other series [23]. In our cases, the collapses were severe and the shoulders had become stiff. When the head is fully collapsed, implantation of a prosthesis can result

in an increase of the joint pressure, causing pain and stiffness. In these cases, RSA [2, 24, 28] or Pyrocarbon Interposition Shoulder Arthroplasty (PISA) could be a better option. Indeed, PISA demonstrated good results for patients presenting post-fracture osteonecrosis, with a mean postoperative Constant' score of 64±33 pts at 24-month FU [9] or of 70±13 pts at 42-month FU [13].

Post-instability OA has also been reported to be a good indication for HSA [16]. This pathology affects particularly young patients. The clinical results obtained in this group were very satisfactory, with a mean Constant score of 80.9±8.5 points at 2-year follow-up and a mean improvement of 50 points as compared to baseline. Conversely, outcomes for the secondary OA post-traumatic group were poor, as already reported in previously published series [25].

The only 2 patients presenting RA did not demonstrate the best outcomes of the series, but they were satisfied by the procedure, mostly because of the pain relief, which is an important consideration for these patients. When the cuff is functional, pyrocarbon HSA might be considered a viable option for patients affected by this specific pathology but a larger cohort is necessary to confirm.

In patients with primary OA without glenoid bone loss and with a centered humeral head (A glenoids), good outcomes were expected. With a mean postoperative Constant score of 80 points (improvement of 45 points compared to baseline), the results were satisfactory as compared to those reported for TSA and HSA in the literature [5, 6, 17].

With this new pyrocarbon implant - using a classic operative technique - outcomes in the Primary OA with B1 and B2 posterior subluxations group were unexpectedly good. The mean postoperative Constant score were 78.8±14.4 (B1) and 77.7±10.0 (B2) points with a mean gain around 45 points as compared to baseline. Indeed, OA is characterized by a cartilage degradation of the joint. When it affects the posterior part of the glenoid (B glenoid) the pressure of the head is no longer applied centrally but eccentrically, resulting in erosion, first of the posterior glenoid cartilage, then of the bone. Once the glenoid is biconcave, it limits the capability of the head to regain a centered position in any arthroplasty procedures [12, 16, 26]. Surprisingly, in patients presenting those B type glenoids, a seemingly re-centering of the humeral head in front of the glenoid was observed in some patients Two main factors could explain this phenomenon: (1) a restoration of the antero-posterior translational movement of the humeral head. Indeed, one of the properties of pyrocarbon is to adsorb proteins and phospholipids on its surface, enhancing the formation of a lubricating membrane which reduces friction [8], thereby facilitating this anteroposterior translation; (2) a preferential paleoglenoid versus neoglenoid bone remodeling as the bone density of the anterior facet (paleoglenoid) has been shown to be lower than that of the posterior facet (neoglenoid) [15]. Thus, the paleoglenoid could more readily undergo a remodeling process to adapt to the humeral head re-centering. Likewise, a slight reduction of the native humeral retroversion, the absence of internal rotation during rehabilitation, or the subscapularis intraoperative release, could also contribute to the humeral re-centering effect. At this stage, considering the short-term follow-up and the small cohort size, the authors would not recommend the use of pyrocarbon HSA for patients with B2 type glenoids. Longer term follow-up, a larger cohort and a thorough radiological analysis will be needed to understand and confirm these observations. However, for young patients with B1 type glenoids, pyrocarbon HSA is considered an acceptable option by the authors, to avoid the risk of long-term complications from TSA or RSA.

Regarding the reported complications, the authors were not able to identify preoperative risk factors for the 3 reported revisions (all patients presenting with OA). However, in young patients, preserving the glenoid and using a convertible stem are 2 major advantages when considering potential future revisions.

Although it is a prospective multicenter exhaustive and continuous series on a sizeable whole cohort, covering a wide range of etiologies, the study showed some limitations: the absence of control group, the small sizes of the cohort of patients within each etiology and the short clinical follow-up. The decision to perform a non-controlled study was motivated by ethical rationale as, given its poor published shortcomings, the authors considered inappropriate to perform metal HSA as a control procedure.

CONCLUSIONS

This study is the first one reporting outcomes of HSA with a pyrocarbon head assembled onto a convertible humeral stem, at a minimum of 2 years follow-up. Pyrocarbon HSA demonstrated good clinical and radiological outcomes in patients presenting primary OA and post-traumatic secondary OA or osteonecrosis. Outcomes in patients presenting fracture sequelae (secondary OA or osteonecrosis) were rather poor. Those findings are encouraging, although they need to be confirmed by longer follow-up observations.

Acknowledgments and funding Information

Acknowledgements

The authors wish to thank Dr. Solange Van de Moortele for her valuable help in coordinating the study and for her assistance with reviewing and editing the manuscript.

Ethical approvals

This study was submitted and approved by the French National Ethic Committee "Comité Consultatif sur le Traitement de l'Information en matière de Recherche dans le domaine de la Santé (CCTIRS)" (EC study number 14209), the German Regional Ethic Committee "Ethik-Kommission der Bayerischen Landesärztekammer" (EC study number 14090), and the Italian Regional Ethic Committee "Servizion Sanitario Regionale Emilia-Romagna" (prot. gen. 0043753).

Conflict of Interest

This study was sponsored by Tornier SAS (Montbonnot, France). J. Garret and A. Godenèche received fees for their participation in collecting and analyzing data. Hopital Pellegrin and Instituto Ortopedico Rizzoli received funding for the conducting of the study in their facilities.

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24/ PLANIFICATION OF FAILED ANATOMIC TOTAL SHOULDER ARTHROPLASTY

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The implantation of a shoulder joint replacement implant is not a new procedure. Neer et al. pioneered this procedure as a hemi-arthroplasty in 1955; a glenoid component was added in 1972 [1]. These non-constrained implants were gradually modified to improve the fit. As typically happens, the expanded indications and the subsequent large number of implantation procedures has increased the number of complications and revisions. In France, hospitalization data (www.atih.sante.fr) indicates that the number of revisions for total shoulder arthroplasty (TSA) has increased 29% between 2006 and 2010; in the same period, the rate was only 10% for knee implants and 1% for hip implants. The nature of these complications differs depending on the type of implant used, anatomical or reversed (Table 1). In a review of 47 studies with non-constrained shoulder implants that were implanted for degenerative or inflammatory conditions and had at least two years follow-up, complications occurred in 906 out of 4010 shoulders, thus at a rate of 22.6% [2]. Surgical revision was needed in 11.2% of these cases, with at least one of the implant components being changed in 7.9% of cases. Most of the complications were on the glenoid side either bone wear in cases of hemi-arthroplasty (20.6%) or loosening in cases of total arthroplasty (14.3%). It is evident from these findings that complications are currently a problem. Their management requires thorough analysis and careful planning that comprise three steps: initial assessment, choice of the treatment indication, and then preparing for and performing the surgical procedure.

	Anatomical Implants
Number of cases	4010
Number of Complications	1595 (39.8%)
Number of revision procedure	451 (11.2%)
Number of component changes	317 (7.9%)
Glenoid loosening	14.3%
Humeral loosening	14% (13% for cementless stem)
Instability	4.6%
Infection	1.1%

Table 1
Main complications associated with total shoulder arthroplasty

1-INITIAL ASSESSMENT

The initial assessment of a problematic shoulder implant involves clinical, laboratory and imaging evaluations. Five questions must be answered:

- is it infected?
- is it unstable, and if so, why?
- is it worn, and if so, why?
- is it loosened, and if so, why?
- how is the rotator cuff?

Detailed history-taking is required to trace the history of the implant. This is easy to do when the evaluator is the one who initially did the arthroplasty. But when it was done at another facility, some detective work is needed to find information on the initial etiology, the patient's preoperative status, the type of implant used, the conditions under which the surgery was performed and the postoperative recovery. The questioning must also determine the patient's complaint, which is typically pain, and uncover two important aspects: the symptom-free period and how the deterioration appeared. The physical examination will specifically evaluate the appearance of the scar and skin, the quality of the deltoid, the range of motion, and will test the rotator cuff, which can be challenging to carry out in a painful, stiff shoulder.

The basic laboratory work-up (complete blood count, erythrocyte sedimentation rate [ESR], C-reactive protein [CRP]) seeks to identify elements suggestive of an infection.

Radiographs under fluoroscopy control form the basis of the imaging evaluations, with AP views in neutral, external and internal rotation, along with a lateral axillary view being performed. These can be supplemented by a CT scan, as long as the artifacts caused by the implant can be eliminated. The next step is to answer the initial five questions.

Is it infected?

Obvious signs are inflammatory changes. In all other cases, an infection must be systematically identified, especially when the shoulder continues to be painful without a symptom-free period, if there is a history of confirmed infection, a history of radiation therapy, rheumatoid arthritis is present, the patient is diabetic or immunocompromised, if the loosening affects both components and if the laboratory findings (WBC, CRP, ESR) are abnormal. If the slightest doubt exists, joint aspiration must be performed under fluoroscopy or CT scan guidance, or a biopsy specimen taken. Any antibiotics that may have been administered blindly in the previous days must be taken

into consideration. The cultures should be kept for at least three weeks so that slow-growing micro-organisms can be identified, especially Cutibacterimum acnes (PA), which is often the cause of shoulder infections. Despite all these precautions, the rate of positive cultures in revisions that were presumed not to be infected is quite high. Kelly and Hobgood [3] found eight positive samples (six for PA) out of 27 revisions (29%). Two of these developed a secondary infection after the revision. Similarly, Topolski et al. [4] analyzed samples from 439 revisions that had no abnormal laboratory or clinical findings. Seventy-five (17%) had at least one positive culture out of the six cultures performed; 45 were positive for PA. Ten developed an infection after the revision, with PA being implicated five times.

Is it unstable, and if so, why?

The instability is obvious when the patient presents at the emergency department with a dislocation. It is more insidious in the context of subluxation or gradually decentering of the humeral head forwards or backwards.

The cause differs depending on if the instability is anterior or posterior. When the instability is anterior (Fig. 1), the main reason is subscapularis insufficiency [5]. More rarely, the anterior instability can be related to problems in humeral version or to faulty positioning of the glenoid component [6]. If the instability is posterior, the main reason is poor implant positioning due to posterior wear of the glenoid that existed preoperatively, especially if it is associated with posterior translation of the humeral head.

Figure 1
Anterior subluxation visible on lateral axillary view, typically a sign of subscapularis rupture

Is it loosened, and if so, why?

Humeral loosening occurs in about 6% of cases [2]. Radiographs are used to confirm loosening in the presence of continuous radiolucent lines or implant migration. The bone stock must also be evaluated to determine the reconstruction method [7] (Fig. 2). The amount of cement in the diaphysis, presence of a plug, centering of the stem, thickness of the cortex must be evaluated, as they come into play when the stem and cement are removed (Fig. 3). On the glenoid side, loosening is the main complication of anatomical shoulder implants. The average rate was 14.3% in Gonzalez et al.'s meta-analysis [2] and it greatly increased over time [8, 9]. Diagnosis is made based on radiographs where implant migration and radiolucent lines greater than 2 mm wide over the entire bone-cement interface (which corresponds to a Mole score of ≥ 12 [10]) are significant findings. Glenoid component migration has been analyzed by Walch et al. [11]. Three loosening mechanisms have been described: superior tilting of the implant in 41% of cases, subsidence into the glenoid cavity in 32.5% of cases and posterior tilting in 26.5% of cases (Fig. 4). Loosening rarely occurs in isolation, thus other factors must be considered: horizontal off-center displacement of the head, rotator cuff rupture, wrong implant positioning, etc. CT scan unquestionably helps in the analysis. It can also help to assess bone loss around the implant (Fig. 5), which is typically labelled as central, peripheral or mixed [12].

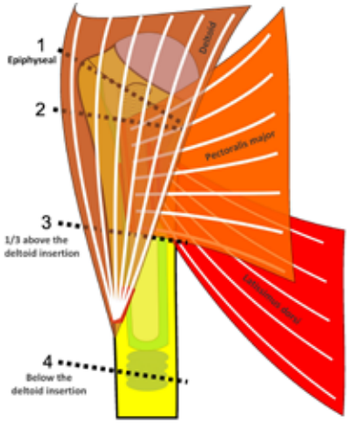

Figure 2
Evaluation of humeral bone stock

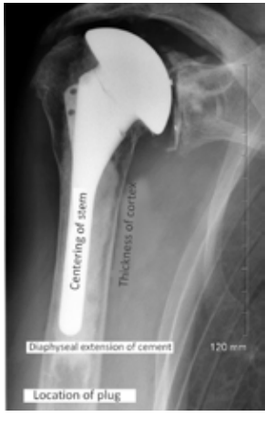

Figure 3
Important aspects to evaluate on the humeral component

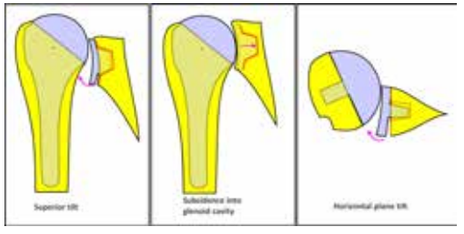

Figure 4
Three types of glenoid component loosening according to Walch

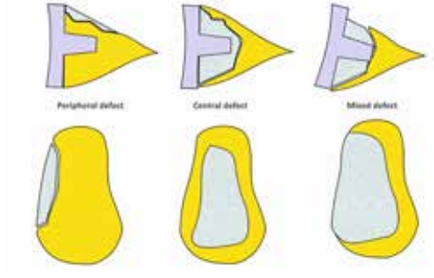

Figure 5
Evaluation of glenoid bone stock

Is it worn, and if so, why?

The thin polyethylene (PE) liner on the glenoid component can be worn, especially in a non-cemented glenoid; this may result in metal-on-metal contact and wear of the metal shell (Fig. 6).

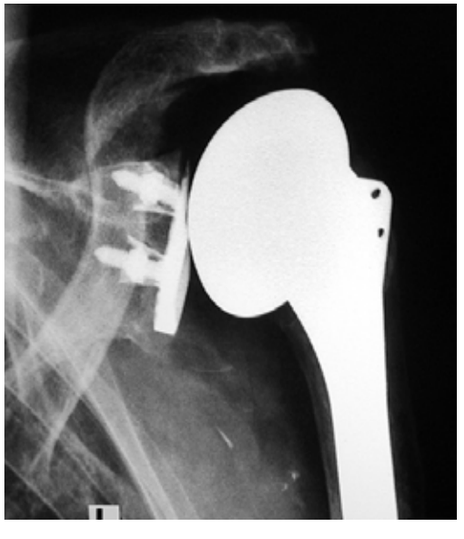

Figure 6
Example of polyethylene and metal wear without associated loosening

How is the rotator cuff?

The rotator cuff is difficult to assess once the implant is in place. Magnetic resonance imaging (MRI) cannot be interpreted. Ultrasonography does not provide any useful information. CT scan of the joint is possible, but artifacts will be troublesome. Also, the rotator cuff may be nonfunctional, even if it is not completely ruptured, as in rheumatoid arthritis. Indirect signs best reflect on the functional status of the cuff, notably the superior migration of the humeral head in the vertical plane (Fig. 7), which can be measured using the method described by Torchia et al. [9]. This abnormal finding has been reported in 46.5% of anatomical TSA cases (19.4% mild, 13.4% moderate, 13.8% severe superior migration) [9].

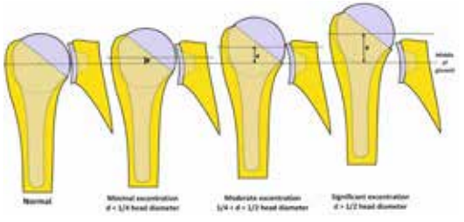

Figure 7
Measurement of humeral head superior migration because of rotator cuff insufficiency according to Torchia

Negative findings

If the answers to all the previous questions are negative, other implant-independent diagnoses must be advanced, such as acromioclavicular problems, a long biceps tendon that has been left behind (0.3% of cases [2]), complex regional pain syndrome characterized by stiffness with no evident etiology. After this assessment, the treatment indication must be determined: is a surgical revision required? If yes, does part or all of the implant need to be changed?

2-INDICATIONS

With glenoid loosening being the most common problem, two scenarios require specific treatment modalities: instability and infection.

Instability cases

With anterior instability, various surgical treatments such as secondary repair of the subscapularis, with or without reinforcement [13], or pectoralis major transfer, are often ineffective. With posterior instability, isolated procedures on the capsule or reorienting the implant components have led to inconsistent results [6]. And no matter if the instability is posterior or anterior, the risk of failure is above 50% [6] and the most effective treatment is RSA.

Infection cases

The treatment choice depends on two aspects: the general and functional condition of the patient and the factors surrounding the infection (early after the surgery, blood-borne, or later on). This decision must always be made after multidisciplinary consultation with infectious disease specialists. The patient's general condition is crucial and if there are no signs of systemic infection, it is often preferable to keep a productive fistula and maintain good function in an elderly or at-risk patient. If the infection occurs early (< 3 weeks) after the surgery or is blood-borne, lavage with debridement and changing of the bearing components (PE liner, potentially glenosphere) leads to good functional results, but more random healing of the infection [14]. If the infection is found later on, removal of the implant, the cement and any foreign body that could host the infection should be considered. Then the choice must be made between one-stage or two-stage replacement, permanent removal of the implant or fusion in specific cases where the deltoid is not functional. The functional results after implant removal are poor [15]. The results of two-stage revisions are poor, except if a cement spacer is used; one-stage revision provides better results [14]. Thus, a one-stage revision is preferable whenever possible: known micro-organism that is sensitive to conventional antibiotics, manageable bone stock, satisfactory patient general condition.

Glenoid complication cases

When determining the course of action relative to the glenoid, remember that working on this component is more complicated with the humeral component present. Appropriate planning requires information about the modularity of the current implant and an evaluation of the possibility of extraction, if this becomes necessary. Many scenarios are possible.

Loosened glenoid component

With an anatomical glenoid implant, published data provide some guidance. Results are better when a new glenoid component is implanted than when only a bone graft is used. Neyton et al. [16] showed that results were best when a glenoid component was reimplanted (Constant score of 58 versus 47.5 with a graft only). However, Cheung et al. [17] could not confirm the superiority of glenoid reimplantation relative to a graft alone in terms of pain or range of motion, only for active elevation. If only a graft is used, cortical-cancellous bone grafts are preferable to cancellous bone grafts. In Neyton et al.'s study [18], the results were better and there was less secondary medialization when a tricortical graft was used.

Over the long-term, the hold of cemented glenoid components is poor. Bonnevialle et al. [19] reported on a 42 patient series in which revision was performed with a cemented glenoid component in every case and with a bone graft also added in 10 cases. After six years, the complication rate was 45%, including seven cases of glenoid component migration. The revision rate was 21%. Radiographs revealed loosening of the new glenoid implant in 67% of cases. This complication was not reported as often in Cheung et al.'s study, but the average follow-up was only 3.8 years [17]. In summary, the type of reconstruction must be planned based on the following criteria (Fig. 8)

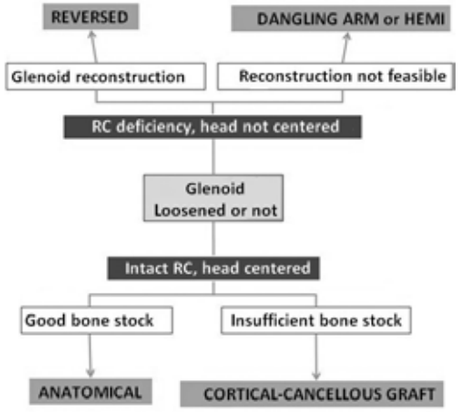

Figure 8
Decision tree for the management of the glenoid component; RC: rotator cuff

- young patient, intact rotator cuff, centered humeral head: an anatomical TSA can be used either by cementing a new anatomical glenoid component if there is minimal bone loss or by reconstructing the glenoid with a tricortical graft (without a glenoid implant) if the bone loss does not allow for reliable fixation of an anatomical glenoid component;
- older patient, rotator cuff deficiency, humeral head off center either vertically or horizontally: consider using a RSA implant and reconstructing the glenoid if necessary. This reconstruction can either be done in a single procedure or in two stages if major reconstruction is needed and the glenoid component cannot be immediately subjected to loading. In every case, the patient's general condition and the amount of his/her disability must be factored into the decision. Sometimes, nothing can be done and the shoulder must be left dangling or only hemiarthroplasty performed to provide an interposition.

Problems with the humeral component

Loosened stem is a rare problem (Fig. 9). Since it has to be changed out, the best extraction method must be chosen while taking into account the bone damage and anticipating that the humerus or tuberosity might fracture. Reconstruction will depend on the remaining bone stock. Non-loosened stem This occurs when the humeral stem is well cemented or has excellent bone integration, but its presence makes it more difficult to work on the glenoid side, or when it must be removed to change to a different implant type (anatomical to reverse arthroplasty), or even when there is an infection or instability present. In determining if the stem can be retained, the modularity of the stem must be known. If it must be removed, certain technical problems are likely. Once the treatment indication has been made, the next step is to prepare for and perform the surgical procedure.

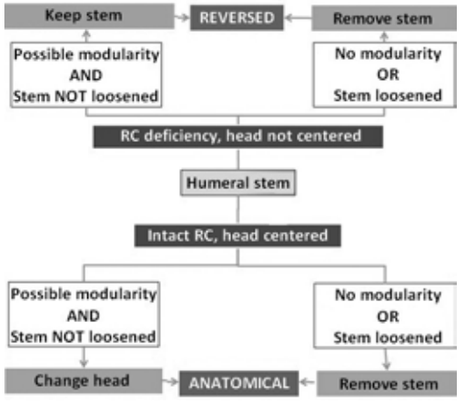

Figure 9
Decision tree for the management of the humeral component; RC: rotator cuff

Preparing for and performing the procedure

Before the procedure, the surgeon must determine the model of the current implant, its modularity, the available extraction instrumentation specific to this implant, decide which type of bone will be used (autograft or allograft) for the humerus and glenoid reconstruction, and have the instruments needed to extract the implant and cement. The patient is placed in the typical position, but will be less seated, as access to the iliac crest is often required. The preferred approach is the deltopectoral route, which allows for easy extension to the humerus in case a humeral window is needed or in case of an intra-operative fracture.

Extraction of humeral stem

Other than in cases of loosening where extraction is fairly easy to perform, extraction of a non-loosened humeral component is difficult, risky and prone to complications, especially humerus fracture (12% in anatomical stem revisions and 30% in reversed stem revisions [20]). Generally, the following steps are performed:

- removal of the humeral head cap when a modular stem is present;
- resection of tissues around the metaphyseal part of the implant and of cement from the upper part (for a cemented prosthesis);
- first attempt at extraction, either using appropriate flyweight-type instrumentation, or using a bone tamp that is placed inside the stem and perfectly aligned with the humeral axis; this avoids a wedging effect, which could result in fracture;
- if the extraction is not successful, a longitudinal osteotomy at the metaphysis and diaphysis junction is made with an oscillating saw outside the bicipital groove [20, 21]. The length of the osteotomy must have been previously determined during preoperative measurements. This slot in the shaft is gradually widened to detach the implant from the cement or the cortex, and then the extraction is attempted again;
- if this fails, a cortical window on both sides of the distal end of the implant can be made if the cement is being preserved or a humeral window can be made if all the cement must be removed. The distal window, cut with an oscillating saw, provides the option to remove the distal cement plug and to push the implant up and out. At this stage, while the humerus is stiffened by the remaining cement, work can be performed on the glenoid, since the humerus can be reflected backwards without much risk of breaking it.

Cement removal

With a loosened stem, the loosening often occurs between the cement and bone, making it easy to remove the cement as it will come out with the stem. With a non-loosened stem, once the stem is extracted, the cement may or may not need to be removed. Other than in infection cases, it is not always necessary to remove the cement, especially if the bone cortex is thin and fragile. Just remove enough cement so that another implant can be added. If the cement must absolutely be removed, this can be done gradually with various instruments, but the safest method is to go through an anterior window [22] or even better, a trans-humeral route [7]. The first osteotomy is performed in the humerus and the second one is performed inside the groove, which results in a vascularized bone window over the pectoralis major, turned inside-out and providing access to the entire cement mantle.

Reimplantation of a humeral stem

The degree of bone loss determines how the stem is reimplanted. A cementless implant can rarely be used. Once the windows have been surrounded by wire cerclage and the radial nerve is safe, a leak-proof bone cylinder exists. A new implant can be cemented as long as its lower end spans beyond that of the window by at least two shaft

diameters. If the bone defect involves the entire humeral metaphysis or more, a reversed implant must be used with an allograft combined with iliac cancellous bone. Chacon et al. [23] proposed using a structural proximal humeral allograft fixed to the native humerus in combination with a humeral implant having a long stem. If the bone loss goes beyond the diaphysis, during tumour excision surgery for example, a massive allograft of the proximal humerus can be combined with a long-stem implant that is cemented at the diaphysis and stabilized with an external plate with at least three screws in each fragment. The major challenge is choosing the correct implant height, which contributes to the risk of postoperative instability. The occurrence of a fracture during the humeral phase requires the use of a long-stem humeral component to bridge the fracture site. During cementing, verify that no cement is extruded as this could cause thermal injuries or radial nerve compression.

GLENOID

Extraction of glenoid component

This is easy to accomplish when the glenoid is loosened, but is more complicated when the glenoid component is still attached. With a cemented component, the PE liner and then the cement can be removed easily. With a non-cemented component, this is harder to do. Carefully and gradually detach the bone from the glenoid base plate and try to limit the amount of bone lost during the removal.

Reconstruction

If the bone is not damaged, a new glenoid component can be implanted. If the glenoid must be reconstructed, the bone loss, evaluated after the implant is removed, and the patient's condition must be taken into account. If a bone graft will be used without implanting a new glenoid component, the preferred approach is to impact a tricortical autograft or to use screw fixation if the graft is unstable. In this case, use of resorbable screws is preferable. If a decision has been made to proceed with reimplantation, a cementless component is preferred as the graft can be fixed at the same time. When a reversed implant is indicated, Norris et al.'s technique is most practical [24]. The iliac crest is opened, then dedicated instrumentation is used to harvest a cortical-cancellous bone graft; this graft is used to fill the bone defect and is placed on the base plate using a hole in the middle of the graft (Fig. 10). The central peg must have purchase in native healthy bone over a length equal to at least twice the diameter of the peg. After the surgery, immobilisation for 45 days is recommended for any extensive or fragile reconstruction cases.

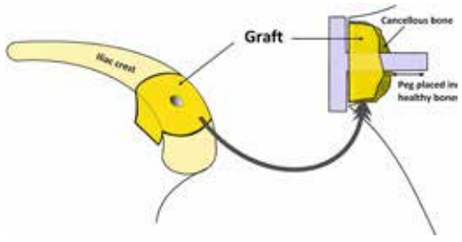

Figure 10
Glenoid reconstruction technique used by Norris for reverse shoulder arthroplasty

CONCLUSION

Revision of shoulder arthroplasty has three possible pitfalls:

- diagnosis error: many abnormal findings on radiographs are not necessarily symptomatic, especially radiolucent lines on the glenoid side. There must be complete agreement between the clinical and radiography findings for the revision indication to be made;
- underestimating the risk of a latent infection: even when the clinical and laboratory findings are not supportive, potential for aseptic loosening exists in 17 to 29% of cases, with PA being present in 50% of these cases;
- poor preparation for the surgical procedure: all the factors associated with instability, wear or loosening must be analysed (implant positioning, rotator cuff intact, patient's condition). The risks and benefits of the chosen indication must be weighed carefully. Every aspect of the procedure must have been planned for, including the possible occurrence of complications and how they will be resolved.

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25/ HUMERAL LOOSENING IN ANATOMIC TOTAL SHOULDER ARTHROPLASTY. EVALUATION AND MANAGEMENT

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BACKGROUND

Humeral loosening with anatomic total shoulder arthroplasty has become a less common problem with the advent of improved ingrowth surfaces. In the past, humeral loosening with shoulder arthroplasty was more common when humeral stems were used in an uncemented manner that did not contain a porous ingrowth surface. Dating back to reports on the original Neer shoulder prosthesis, the rate of lucency with humeral stems used in an uncemented manner with anatomic total shoulder arthroplasty was reported to be greater than 50% (1).

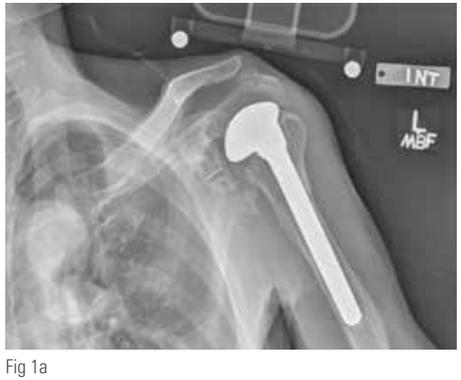

Fig 1a
A classic example of an infected shoulder arthroplasty with a loose humeral component

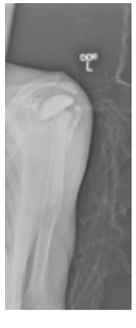

Fig 1b
Placement of an antibiotic spacer

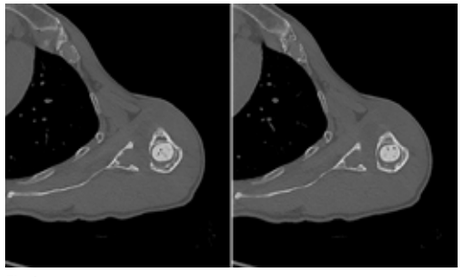

Fig 1c
CT scan demonstrates associated glenoid bone loss

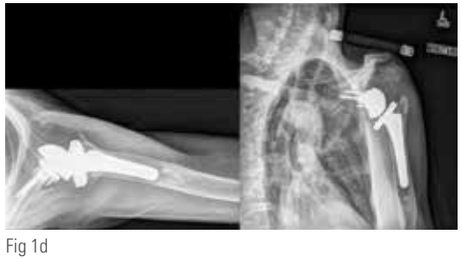

Fig 1d
Revision to reverse with shorter stem

The advent of porous ingrowth surfaces has dramatically decreased the rate of humeral loosening with anatomic shoulder arthroplasty. These porous surfaces were specifically designed for bone ingrowth. Stem modifications included circumferential metaphyseal porous coating among some implants. Throckmorton reported on the outcome of 76 uncemented stems used with anatomic total shoulder arthroplasty at a mean follow-up of 4.3 years. (2) At the most recent follow-up there were 5 stems with an incomplete lucent line. There were no components with a shift in position or that were loose.

Fig 2a
Loose humeral component

Fig 2b
Reconstruction of the humerus with an SRS implant

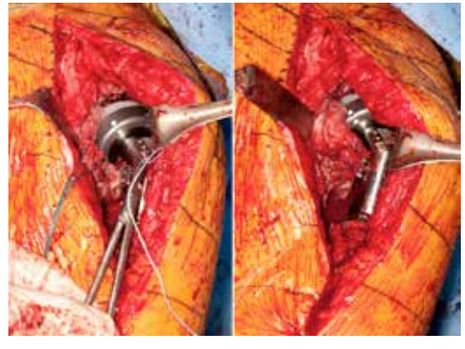

Fig 2c
Sewing the subscapularis to a soft tissue reattachment pad

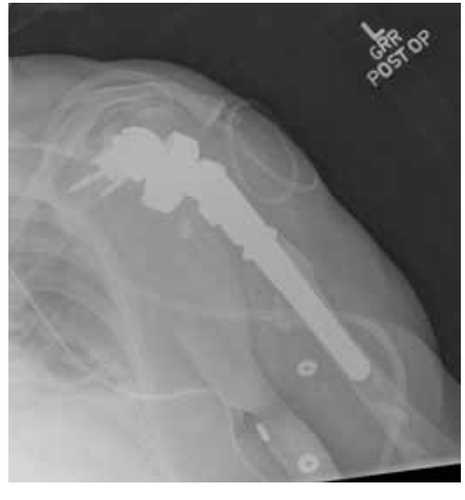

Fig 2d
Post-op radiograph

These low rates of humeral lucency subsequently facilitated the development of shorter humeral stems. Stem length decreased from standard length 122 mm to 83 mm and then down to 55 mm in some systems used for anatomic and reverse arthroplasty. (3) The success with the short humeral stem subsequently facilitated the development of stemless shoulder arthroplasty.

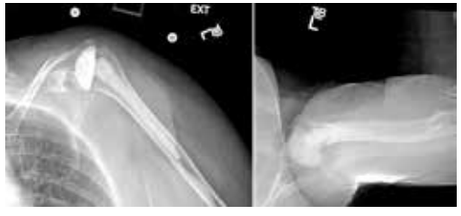

Fig 3a
Example of a spacer mold. The patient was started on immediate passive motion exercises to minimize stiffness

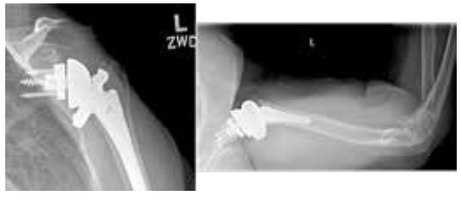

Fig 3b
Example of a revision with a short stem and an augmented glenoid component that was used in a bone preserving manner. The augmented glenoid component is used to create the glenoid tilt rather than reaming away central and inferior glenoid bone stock

EVALUATION OF HUMERAL COMPONENT LOOSENING

In the modern era of anatomic shoulder arthroplasty, the primary reasons for loosening are stem designs with an inadequate porous ingrowth surface, significant stress shielding leading to loosening, osteolysis from polyethylene wear, and infection. The first two reasons are implant dependent. (4) Norris reported on the outcome of 73 short stem press fit components used in anatomic shoulder arthroplasty with 71% having humeral radiolucency. Therefore the surgeon should be aware of the specific implants that have had these problems. Polyethylene wear and associated osteolysis of the humerus is more frequently seen in longer follow-up and usually has associated glenoid loosening. Serial radiographs are helpful to evaluate for a shift in component position, timing of development of loosening, and associated bone loss.
In the absence of a specific component design issue, infection is the most likely reason for loosening. It is important to determine if there is a history of wound complications,

drainage, or post-operative use of antibiotics. The work-up of the patient with a loose humeral component includes blood work: complete blood count, sedimentation rate, and C-reactive protein. Patients also undergo an image guide aspiration with cultures that are kept at least two weeks. A CT scan is performed as well to evaluate loosening, but may be limited due to metal artifact even with specific metal suppression software.

REVISION-NOT INFECTED

In the case of a loose humeral component in the non-infected setting, with a standard length stem, the decision in the authors practice is to determine if revision to a shorter stem if possible. If a 122 mm stem is removed, typically an 83 mm stem is used. This helps prevent associated problems with long stem components. Additionally, we prefer to use an uncemented stem. The only setting where we consider cement is when a proximal humeral replacement is used in the setting of multiple prior surgeries with poor quality bone. The majority of patients currently undergo revision to reverse arthroplasty with an uncemented short stem.

REVISION-INFECTED

In a patient with a chronic infection, the most accepted treatment is a two stage procedure. (Figures 1-3) A major advance is the use of cement spacer molds in a variety of sizes. This allows the surgeon to template the case and the spacer can be made while the patient is going to sleep for surgery. This can save 20 or 30 minutes of operative time and facilitates an efficient procedure. The surgeon can decide on the specific type and amount of antibiotics in the spacer mold, Moreover, the spacer molds allow immediate motion which has been shown to result in improved post-op motion compared to patients that are immobilized. (5)

SUMMARY

Loosening of the humeral component in anatomic shoulder arthroplasty has become less common. When encountering this problem, the surgeon should carefully evaluate the humeral component that was utilized and be aware of those designs at higher risk for loosening and stress shielding. Additionally, there needs to be a high suspicion for infection and a work-up for infection may be beneficial

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26 / FAILURE OF ANATOMIC TOTAL SHOULDER ARTHROPLASTY (ATSA): GLENOID LOOSENING IN ATSA HOW TO DEAL AND RESULTS

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INTRODUCTION

The fixation of the glenoid component still seems to be the most important limiting factor for implant survival of cemented all-poly glenoid components of ATSA in the mid- to long-term. Although considerable thought has been spent on different design modifications, it does not seem to have influenced the long-term survival and revision rate much. Therefore glenoid loosening is a very common problem which can be expected at least in 45% of cemented components after 10 years and 65% in 15 years (Young et al. 2011 and 2012). Moreover most of the metal-backed anatomical glenoid components revealed unacceptably high failure rates even at mid-term follow-up (Papadonikolakis et al. 2014), often complicated by early breakage of screws and titanium wear which may lead in some designs to a "catastrophic" failure (Vuillermine et al. 2015).

Advanced glenoid bone loss in case of loosening of anatomical total shoulder arthroplasty can be a challenging problem because a combination of different pathologies has to be addressed:
- advanced glenoid bone loss,
- osteolysis in the glenoid and proximal humerus caused by PE wear
- rotator cuff atrophy and fatty infiltration
- periarticular scarring
- low grade infections

Because the conversion of non-modular humeral components to reverse TSA is rarely possible, the removal of well-fixed stems through a split or humeral window (Gohlke et al. 2007) is in revisions required.
In principle glenoid loosening of ATSA can be treated with different options:
- Arthroscopic or open debridement and removal of the glenoid component with or without bone grafting
- Exchange of the glenoid component to a cemented or cementless metal backed anatomical glenoid component with or without bone grafting
- glenoid reconstruction and conversion to reverse TSA in a one stage or two stage procedure, using autograft, allograft or custom made implants as bone substitute.

In literature numerous reports (Neer and Kirby 1982, Cofield and Edgerton 1990, Brems et al. 1993, Wirth and Rockwood: 1994 , Peterson and Hawkins 1998, Antuna et al. 2001 and 2002, Cheung et al. 2008) proof evidence of unpredictable, often unsatisfactory improvement in revision of anatomical shoulder arthroplasty for glenoid loosening before reverse shoulder replacement (RSA) was introduced for revision arthroplasty by DeWilde (2001). This was related mainly to persisting rotator cuff insufficiency, recurrence of instability and low success rates after reconstruction of glenoid bone stock. The reverse implants showed higher success rate treating all three key problems (Melis et al. 2012) but included more problems on the humeral side: Need of removal of anatomical stems which do not offer the option of conversion (Werner et al. 2013) and higher rates of stem loosening and further humeral bone loss (Werner et a. 2016) in the long run. Recently published papers (Norris 2007, Wagner et al. 2015) show that revision to RSA is a reasonable option but still related to high complication rates (Melis 2012). Moreover the success rates in case of glenoid loosening were rarely analyzed regarding the amount of bone loss and destruction pattern.
This is probably caused by difficulties to assess glenoid bone loss because preoperative imaging even with newest technology of CT based imaging (dual energy technique) remains often difficult due to metal artefacts. Bulky humeral components, metal backed glenoid components and advanced titanium particle wear do mostly seriously interfere.
Therefore in case of suspicion of low grade infection and unclear CT findings (e.g. pistoning of PE glenoid component in the intact cement mantle) we prefer arthroscopic assessment which provides additionally valuable information about the remaining bone stock.

We use for pre-OP planning a modified Antuna classification (Gohlke et al. 2017, see table 1) in order to have guidelines for proper implant selection, surgical technique and the use of bone grafts (autologous/allografts):

Type 1:
Mild bone loss (centered or eccentric [=peripheral]<15°)

Fixation is easy to perform with anatomical and reverse glenoid components. Mostly no structural graft is needed for reconstruction, sometimes cancellous bone obtained from the proximal humerus or glenoid reaming. The failure of retroversion or inclination may be compensated by bone graft or augmented implants.

Type 2:
Moderate bone loss, the glenoid vault is intact

The transfixation technique acc. to Norris (2007) is mandatory in most of the cases when RSA is preferred. For anatomical TSR a metal backed baseplate with long post is as well required. The bone defect is preferably filled using a cortico-cancelleous autologous graft from the iliac crest. Cancellous bone provides less primary fixation strength. A minimum of two, better 4 locking screws improves the stability. Structural allografts may be used as further option. A minimum of 10mm of a coated post should be seated in the remaining native bone stock for ingrowth because resorption or collapse of the allograft under the base plate can be expected.

Type 3:
Severe eccentric bone loss (> 20°), the glenoid vault is not intact; one wall is broken or deficient

This problem is more difficult to solve for the surgeon and requires experience, modern implants and different techniques of reconstruction. Autologous bi- or tricortical iliac crest bone graft is preferred. One stage procedures are possible, when the primary fixation strength is acceptable. We already described the technique of intra-operative testing for advanced eccentric bone loss in neglected anterior dislocation (Werner et al. 2014): Testing was performed during gentle movement of the baseplate impactor after hammering in the baseplate. In doubt the surgeon should prefer a staged operation.
To achieve reliable baseplate fixation, slight alteration of the glenoid centerline (<10°) is recommended. No data are given in literature on the optimal anchorage length of the central post to ensure primary stability of the baseplate. We feel that the central peg of the glenoid baseplate should access a minimum of 10 mm of the native glenoid for reliable fixation.

Type 4:
Severe bone deficiency and breakage or excessive medialization of both posterior and anterior wall of the glenoid vault

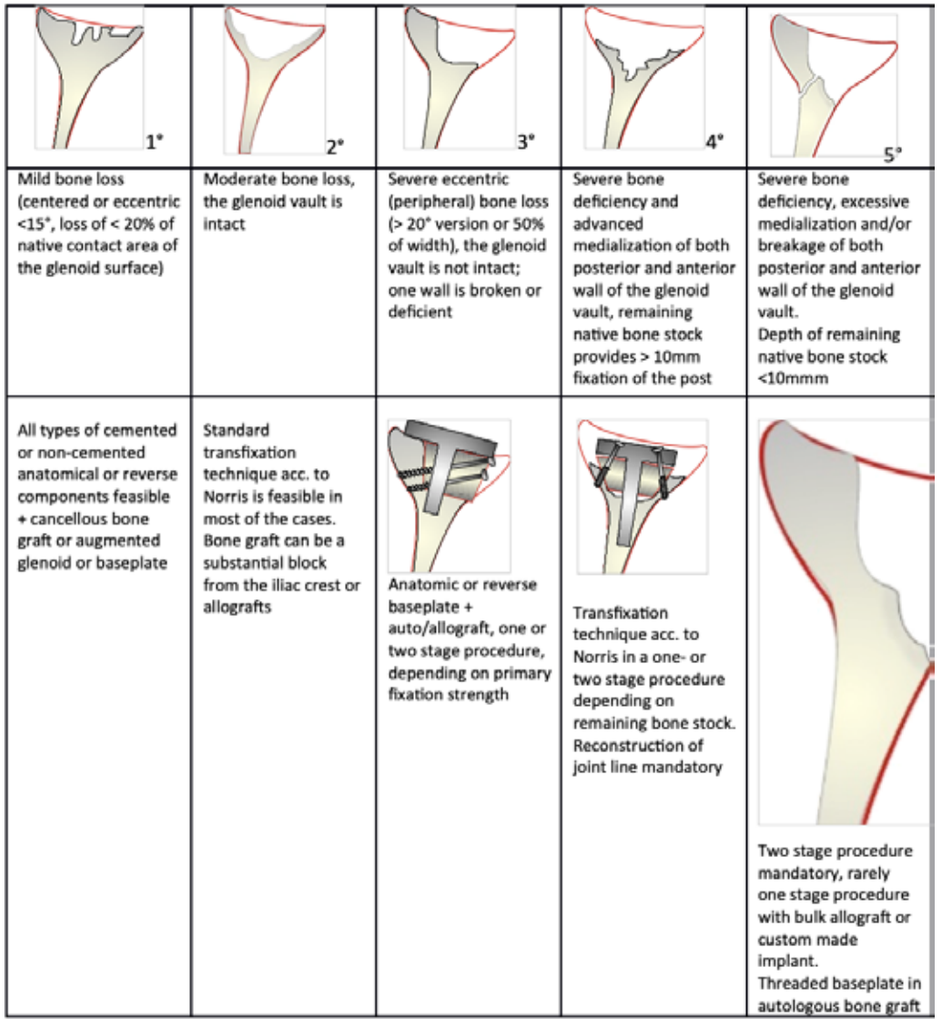
The remaining bone stock does not provide stable fixation of a peg or screw to native bone, even with a bulk bone graft. Mostly we prefer reconstruction with autologous iliac crest bone graft in a two stage procedure when the primary fixation strength is expected to be too low. In younger male patient even in these cases the remaining bone stock may offer a more solid fixation in combination with bulk allografts or substantial autograft. Especially in elderly women suffering from advanced osteoporosis and/or rheumatoid arthritis the remaining bone stock can be very weak. Further options are custom made implants but preoperative planning may be difficult due to hardware artefacts in the CT scan.

Type 5:
Severe bone deficiency and medialization of both posterior and anterior wall of the glenoid vault

The remaining bone stock provides hardly fixation of the central post or screw in the native bone stock, even with a bulk bone graft. When the primary fixation strength is doubtful we prefer reconstruction with an allograft or iliac crest autograft in a two stage procedure. In younger male patient the remaining bone stock may offers a more solid fixation in combination with bulk femoral head allograft or substantial autograft.

Type 6:
Severe bone deficiency and breakage or excessive medialization of both posterior and anterior wall of the glenoid vault

The remaining bone stock does definitely not provide stable fixation of a peg or screw in native bone stock, even with a bulk allograft. Especially in elderly women suffering from advanced osteoporosis and/or rheumatoid arthritis the remaining bone stock can be very weak. We prefer reconstruction with autologous iliac crest bone graft in a two stage procedure or rarely one stage reconstruction with bulk femoral head allograft. Further options for type 4 and 5 are custom made implants but preoperative planning may be difficult due to hardware artefacts in the CT scan.



1°	2°	3°	4°	5°
Mild bone loss (centered or eccentric <15°, loss of < 20% of native contact area of the glenoid surface)	Moderate bone loss, the glenoid vault is intact	Severe eccentric (peripheral) bone loss (> 20° version or 50% of width), the glenoid vault is not intact; one wall is broken or deficient	Severe bone deficiency and advanced medialization of both posterior and anterior wall of the glenoid vault, remaining native bone stock provides > 10mm fixation of the post	Severe bone deficiency, excessive medialization and/or breakage of both posterior and anterior wall of the glenoid vault. Depth of remaining native bone stock <10mmm
All types of cemented or non-cemented anatomical or reverse components feasible + cancellous bone graft or augmented glenoid or baseplate	Standard transfixation technique acc. to Norris is feasible in most of the cases. Bone graft can be a substantial block from the iliac crest or allografts	Anatomic or reverse baseplate + auto/allograft, one or two stage procedure, depending on primary fixation strength	Transfixation technique acc. to Norris in a one- or two stage procedure depending on remaining bone stock. Reconstruction of joint line mandatory	Two stage procedure mandatory, rarely one stage procedure with bulk allograft or custom made implant. Threaded baseplate in autologous bone graft

Table 1
Algorithm for different types of glenoid bone loss (Gohlke et al. 2017)

PERSONAL EXPERIENCE

From 2008-2016 we identified 145 cases of revision total shoulder arthroplasty suffering from moderate or advanced bone loss which were retrospectively evaluated and 95 followed up for mean 2.7 years (1-7 years). We classified the remaining bone stock as 4° or 5° in 61 patients and 2° and 3° in 84 patients. Our preferred surgical technique was the cementless fixation of structural bone grafts using a reverse baseplate in transfixation technique. 56 cases required substantial iliac crest bone grafts, of which 36 patients were operated on in a 2-stage procedure. In 20 patients the bone defect in the iliac crest was secured by a locking plate in order to avoid a fatigue fracture of the anterior iliac spine. Only in 5 cases with intact rotator cuff an anatomical "platform" component was used, the remaining cases were converted to reverse shoulder arthroplasty. 56 required substantial iliac crest bone grafts, of which 36 were operated in a 2-stage procedure. In 20 patients the bone defect in the iliac crest was secured by a locking plate in order to avoid a fatigue fracture of the anterior iliac spine. We classified the remaining bone stock as 4° or 5° in 61 patients and 2° and 3° in 84 patients. In all cases baseplates with a long post and locking screws were used. 5 cases were converted to an anatomical "platform" component, which offers the option of conversion to a reverse implant.

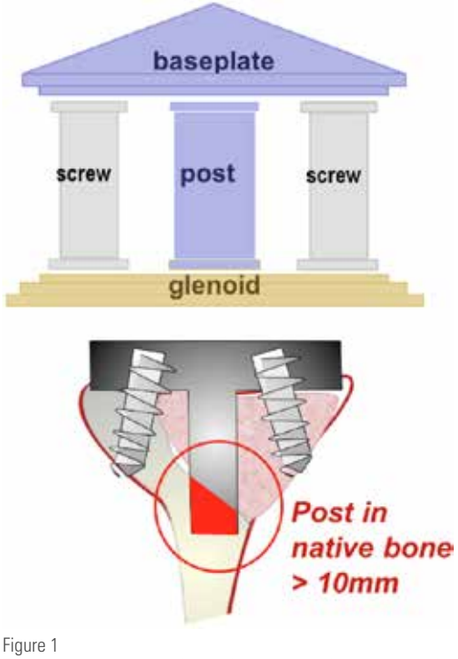


Figure 1
Three column concept of glenoid reconstruction as composite auto-/allograft reconstruction with cementless baseplate.

The surgical technique of glenoid reconstruction was adapted to the remaining bone stock and type of implant. Both pre-OP CT planning and intraoperative testing of the stability of the implant were used for decision making. In most of the cases RSA was combined in a one- or two-staged procedure with autograft from the iliac crest or with allografts (fresh frozen proximal humerus or femoral head). The preferred fixation mode was the transfixation technique acc. to Norris (2007), using baseplates with extra-long coated or threaded post with 2-4 locking screws. The success rate (absence of clinical or radiographic signs of loosening) was 94,2% in one stage procedures and 96,7% two stage revisions [11].

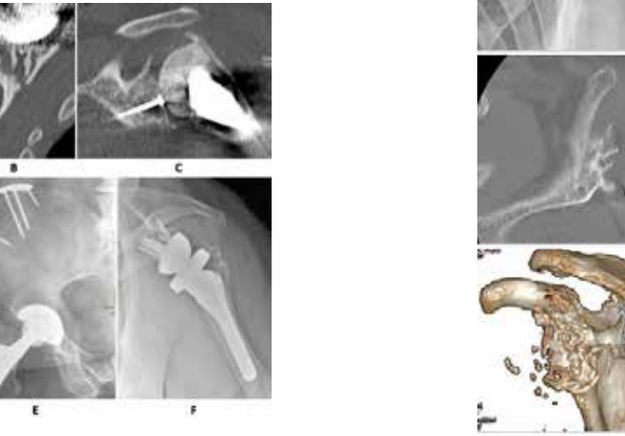


Figure 2
Two staged procedure in type 5 glenoid deficiency (glenoid vault and neck broken) 15 years after anatomical stemmed total shoulder and glenoid loosening.
A: ap-ray, B: CT scan shows glenoid destruction and "floating" glenoid, C: CT scan after autograft reconstruction and spacer with the modular stem still in place, E: plating of the donor site in order to avoid fatigue fracture, F: final X-ray after conversion to RSA

Complications: We observed three dislocations and in both groups one case of a fatigue fracture of the glenoid neck each. In 2 cases a fatigue fractures of the scapular spine occurred 8 and 14 weeks after surgery, all treated conservatively. All fatigue fractures occurred in female elderly patients with advanced osteoporosis. In the group of one-stage glenoid reconstruction we found in two patients glenoid loosening with partial bone resorption, both were revised, one again with autograft the second with femoral head allograft.
In the two-staged glenoid reconstruction group (only performed in type 4 and 5 bone loss) we needed a second performed revision with both auto- and allograft after 1 year.

We found a correlation of the clinical results with the amount of bone loss and complexity of surgical procedures. In most of the cases both the glenoid reconstruction and the surgical procedure on humeral side, often complicated by advanced humeral boen loss due to loosening or PE wear as well as rotator cuff insufficiency , periarticular scarring and delta muscle weakness influenced the result.

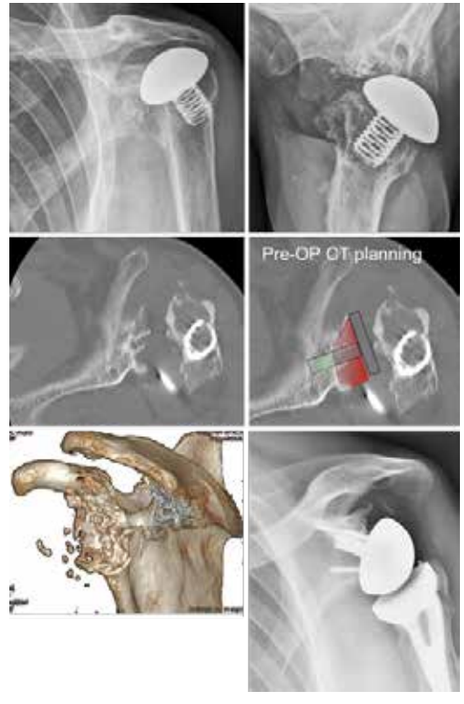


Figure 3
Revision of failed ATSA in a 46yo. male patient 4 years after stemless ATSA and pectoralis major transfer for fracture sequelae done alio loco: Type 4° bone loss and posterior-superior subluxation.
Glenoid reconstruction was performed using iliac crest autograft in Norris-technique. Correction of 20° superior inclination and 25° retroversion reconstructing the joint line with 20mm lateral offset. The post was seated 13mm in the remaining native bone stock.

DISCUSSION

Most of the studies dealing with the treatment of glenoid loosening are focused on anatomical implants treated with removal of the components, bone grafting and/or re-implantation of anatomical components (Antuna et al. 2001, Phipatanakul 2006, Deutsch et al. 2007, Cheung 2008, Aibinger 2016). They report a "reasonable" improvement in terms of pain relief rather than active ROM for all groups especially in patients with intact rotator cuff and absence of instability. Patients with re-implantation of a glenoid component do slightly better than conversion to a hemi with bone grafting. However, Bonnevialle et al. describe unfavorable results with a high rate of loosening after re-implantation of a cemented glenoid component. Autograft reconstruction of the glenoid is reported to result often in subsidence Neyton, et al. (2006), and later by Ianotti et al (2012). In their series, however, the humeral head replacement directly contacted the bone graft. Because we observed as well progressive resorption of bulk allograft with a thickness of > 20mm we preferred autografts from the iliac crest even when the morbidity of this procedure was higher. Nevertheless due to the increasing age and poor health status of many patients we used within the last years an increasing number of structural allografts (mainly fresh frozen femoral head) mainly in order to avoid the donor morbidity. Recently Ozgur et al. (2017) reported a much higher failure rate of cortical femoral neck allografts in revision RSA comparing to femoral allografts.

Reports about glenoid reconstruction and revision to reverse arthroplasty are few. Kelly et al. described 2012 a high success rate after revision RSA for failed anatomical shoulder arthroplasty of which in 12 patients glenoid a reconstruction with tricortical iliac bone graft was necessary. With the exception of 1 patient with an infection, all of the bone autografts healed to the native scapula. Patients with glenoid reconstruction achieved comparable results and gain of function as patients without glenoid bone loss. The transfixation technique of Norris et al. (2007) was used in all cases.
Melis et al. (2012) reported clinical and radiological results of 37 patients after revision to reverse shoulder arthroplasty for glenoid component loosening. The amount of bone loss was not classified, but twenty-nine patients underwent glenoid bone grafting and structural iliac crest bone was used in 21 patients, cancellous bone graft in 5, and allograft in 3. Complications occurred in 30%, revisions in 22%. The Constant score improved to 55.2 points. At the latest follow-up, they observed 1 case of bone graft lysis, and partial graft resorption was present in 21% of patients.
Walker et al. (2012) described revision of anatomical TSA with RSA in 24 patients, mostly done for instability rather than glenoid loosening. The classification of Antuna was used but the amount of bone loss not described. However, bone graft was used in 15 patients (68%), of which 10 grafts were structural femoral head allografts. All but 1 (loosening without revision) of the structural allografts showed evidence of incorporation on final radiographs, and all 5 nonstructural allografts were incorporated.

CONCLUSION

The treatment of glenoid loosening has experienced fundamental changes since the introduction of reverse shoulder arthroplasty because rotator cuff deficiency and instability are successfully addressed. Glenoid baseplates with extra-long central post and locking screws allow even in case of severe glenoid bone loss successful glenoid reconstruction using autograft and allograft.
Nevertheless it is still a challenging procedure even for the experienced shoulder surgeon who needs proper pre-operative planning and technical support. Durable fixation and graft healing can mostly be achieved even in demanding cases with one- or two-stage procedures but the revision rates and complication rates are high. Additionally, after multiple operations and concomitant severe damage of the soft tissue envelope the clinical results are often limited.

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27 / FAILURE OF ANATOMIC TOTAL SHOULDER ARTHROPLASTY: REVISION OF FULL PE

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Rationale

Glenoid component loosening is a major cause of failure of total shoulder arthroplasty. When the glenoid component fails and loosens, small to large cavitary and/or peripheral lesions are created in anatomically small bone volumes. To date, defects are either neglected or managed with reconstruction techniques utilizing isolated or mixed autograft, allograft or bone graft substitutes.

The goal of glenoid reconstruction is to provide a solid area and a fulcrum point in front of the prosthetic head. Therefore, an ideal reconstruction technique should offer sufficient primary resistance, heal to the native glenoid, avoid secondary subsidence, and resist humeral head medialization. Moreover, glenoid reconstruction should allow component reimplantation at the same time or in a staged procedure either with anatomic or reverse prosthesis.

SIMPLE LOOSE GLENOID COMPONENT REMOVAL

Isolated removal of the loose glenoid implant is a simple procedure avoiding the problem with reconstruction of the glenoid bone stock. The removal of the loose glenoid implant is performed through a revision deltopectoral approach and through the rotator interval avoiding subscapularis re-violation. The procedure can also be performed arthroscopically[11].

This procedure provides acceptable results in regards to pain, but low mobility and function because medialization of the humeral head and wear of the remaining glenoid bone reduces the rotator cuff and deltoid moment arms[5,6]. Absence of glenoid reconstruction precludes, a priori, further glenoid re-implantation. This option should be indicated in frail or non motivated patients and be considered as a limited goal procedure.

IMPACTION BONE GRAFTING OF THE DEFECT WITHOUT COMPONENT REIMPLANTATION

Impaction bone grafting is the technique of choice when the humeral component is well fixed and rotator cuff efficient to stabilize and center the humeral head. It may also be considered as the first stage before reimplantation after healing of the graft. Many options are available: morsellized or structural bone graft, as well as, allograft, autograft or bone substitute.

Packed Morsellized Cancellous Bone Graft

Morselized cancellous graft is used to fill central cavitary contained defects i.e glenoid vaults are intact or near intact. Cheung and Cofield impacted morselized cancellous allogenic bone grafts (CanPac, AlloSource) in the glenoid defect and noted subsequent mean medialization of the humeral head in relation to the glenoid of 7.5mm. Despite this medialization, second-stage glenoid component implantation was possible and the results of seven cases were evaluated at an average follow-up of seventy-nine months. Pain scores significantly improved, but range of motion did not, with an average anterior elevation of 88°. 2 Similar subsidence was observed by Scalise and Iannotti with a mean 7mm medialization.[13]

In order to promote new bone formation, various osteoinductive, osteoconductive or osteogenic products are available on the market. Norris and coworkers recommend mixing the allograft with osteoinductive demineralized bone matrix. Results reported were satisfactory with pain relief but progressive graft subsidence was observed in 50%.[9] Peidro et al reported (case report) the use of cancellous allograft with platelet-derived growth factor to increase osteogenic activity. Early revision for glenoid component implantation because of continued pain offered the opportunity for laboratory analysis. Histologic examination showed that there was no ingrowth of new bone without any osteoblastic activity or osteoid formation.[12]

Our experience using cancellous allograft has been similar and resulted in severe compression and/or resorption of the graft with medialization of the humeral head and loss of anterior elevation within one year after surgery.

Structural Allograft

Structural reconstruction is indicated in non contained defect i.e the glenoid vault (anterior and/or posterior) is involved. Frankle et al reported the results with bulk allografts and observed graft resorption in four patients out of eleven.[4] Scalise and Iannotti experienced subsidence of bulk allograft in all of their five patients with a mean 14 mm medialization.[13] Elhassan and Warner reported the results of bulk allograft with additional interposition arthroplasty using Achilles' tendon allograft and fascia lata autograft resurfacing without benefit in regards to the Constant score or range of motion.[3]

These findings prompted us to use iliac crest structural corticocancellous autograft, with the cortical surface opposed to the humeral head to provide some structural integrity and resist medialization.

Structural Corticocancellous Autograft (iliac crest)

We use a bulk autograft in central cavitary defects as well as in peripheral defects. In cases with intact glenoid vaults, the graft is contoured with a burr or a rongeur and impacted in the central defect. Additional cancellous bone chips harvested in the same time are used to complete the reconstruction. Impaction in a contained defect provide sufficient primary stability to the graft.

In case of central and peripheral defects the graft is secured to the remaining glenoid with screws. Lateral to medial screw fixation is at risk of contact with the humeral head resulting in metallosis. If deemed necessary, bioabsorbable screws can be used. In case of peripheral defect we use internal fixation of the graft with screws placed in an anteroposterior direction.

REIMPLANTATION OF A CEMENTED POLYETHYLENE GLENOID WITH OR WITHOUT BONE GRAFTING

Glenoid bone defect is filled with cement and the glenoid implant is fixed in the cement. The results have proven to be significantly better compared to simple removal.[1,5,7] This option is reliable when the bone defect is minimal, thus permitting new glenoid implantation in an optimal condition with an intact rotator cuff. On the other hand, a larger defect filled with cement is at risk for recurrent glenoid loosening.

Reconstruction of glenoid deficiency and placement of a glenoid component has been successful in patients with primary TSA. However, this technique is rarely used in revision total shoulder arthroplasty. In our experience, glenoid reconstruction has shown to be inadequate to create a framework necessary to secure a cemented glenoid component and has thus led to early failure.

Bonnevialle demonstrated that revision of a TSA with reimplantation of an all-PE cemented glenoid component with or without bone grafting does not solve the problem of glenoid loosening. Soft-tissue failure and prosthetic instability are underestimated preoperatively and may explain, in part, the high rate of recurrent glenoid loosening (67%) [14].

REIMPLANTATION OF AN UNCEMENTED COMPONENT FIXED WITH SCREWS WITH OR WITHOUT CANCELLOUS BONE GRAFT

Anatomic implant

This option allows both bone stock reconstruction and glenoid component reimplantation.

Revision with an unconstrained glenoid component is possible only with an intact rotator cuff. Antuna et al reported eight cases: 3 cases with small contained defect and 5 with cancellous bone graft. Although pain relief was satisfactory, radiolucency around the glenoid was present in 42%.[1]

More recently, Valenti demonstrated that revision with a noncemented glenoid component associated with a bone graft can solve the difficult challenge of glenoid loosening, provided that the rotator cuff is functional and the glenoid is reconstructable[16].

Reverse implant

Revision with a semi-constrained reverse prosthesis and glenoid bone grafting is another option.[8,10, 15] The metal-backed part of the glenoid allows at the same time bone grafting of the defect and fixation with the four peripheral screws. It is crucial for the central peg to be anchored in the native glenoid rather than solely into the graft. Thus, in a minimal contained defect, morcellized cancellous bone is impacted and a regular or extra-long peg is selected. In larger cavitary and/or central defects it is more suitable to restore glenoid bone stock with a structural graft. This procedure can be performed in either single or staged procedure, as proposed by Norris.[10]

Revision with a RSA is a reliable therapeutic option which provides the double benefit of glenoid

bone stock reconstruction by fixing the bone graft with the help of the baseplate and screws and of solving the problem of soft tissue insufficiency and prosthetic instability. However, surgeons should be aware that the rate of postoperative complications and subsequent reoperations is high, and that the surgical technique is demanding[15].

	Simple removal	Structural ICBG	Cemented PE	Reverse prosthesis+graft
AAE(°)	95°	114°	129°	128°
ER (°)	32,5°	30°	43,7°	17,7°
IR	sacrum	L3	L2	Buttock
Pain (15 points)	9,8	8	9,4	12,5
Constant score (pts)	42,5	50	57,8	53

ICBG : iliac crest bone grafting
Results of different options6,7,8

CONCLUSION

Many options are described for the management of failure of a cemented PE glenoid in revision shoulder arthroplasty. Our experience and analysis of the literature demonstrate mechanical insufficiency of allografts (cancellous or structural) with progressive subsidence of the graft and medialization of the humeral head. On the other hand, structural autogenic iliac crest reconstruction offers more adequate resistance to medialization and allow glenoid (anatomic or reverse) reimplantation in a single or staged procedure.

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28/ ADVANTAGES OF MODERN CONVERTIBLE ANATOMIC SHOULDER REPLACEMENTS

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Along with increased primary procedures, revision arthroplasty burden also increases (1) with growth rates exceeding those of hip and knee arthroplasty. The estimated rate of revision for failed shoulder arthroplasties has increased making revision surgeries account for up to 10 % of all shoulder arthroplasty procedures (1,2,3).
Conversion of prior anatomic total shoulder arthroplasty (aTSA) to a reverse shoulder arthroplasty (rTSA) can be technically demanding and fraught with complications. These challenges led to the recent introduction of a platform system for shoulder arthroplasty, which can include a convertible modular humeral stem and/or a metal-back glenoid component to facilitate straightforward conversion from either a hemiarthroplasty or aTSA to a rTSA without removal of the stem or glenoid baseplate (4).

History of Convertible Shoulder Replacement Systems

In 2003 Kany et al. (4) developed a totally convertible shoulder total prosthesis with a modular shaft and a modular cementless metal-back glenoid (ArrowTm; FH Orthopedics, France). Only one year later Castagna and Lima company in Italy developed a completely convertible anatomical shoulder prosthesis. In 2005, Zimmer launched the Gerber-developed anatomical total shoulder prosthesis as an inverse and thus convertible implant on the market. Meanwhile, there are convertible versions available of mostly all manufacturers who manufacture stem and short stem prostheses.

Advantages of a Humeral Platform System

Revision-to-reverse shoulder arthroplasty has been shown to have favorable results, though complication rates have shown to double as many compared to those of primary procedures (5). Crosby et al. (6) retrospectively reviewed 102 revision anatomic total shoulder arthroplasties to reverse shoulder arthroplasty, of which 29 retained the convertible-platform humeral component. They demonstrated shorter operative times, less blood loss, and lower complication rates in those patients where the humeral component was retained.
For removal and reimplantation of a humeral stem shaft corticotomy is often required, which is associated with a high rate of fracture (7,8).One recent study noted a 21 % intraoperative humeral shaft or tuberosity fracture rate during stem removal for conversion to rTSA (9).Other studies have noted humeral fracture rates of up to 25 % during stem removal at revision (4,8). Additional risks of humeral stem removal include potential loss of humeral bone stock, nerve injury, periprosthetic fracture, and malunion or nonunion of a humeral osteotomy with later humeral component loosening (7). Complications occurred in 24 % and 24% of the patients rated their result as dissatisfied (10).
The use of a platform system virtually eliminates the risk of intraoperative humeral fracture. A recent study reported a 0 % rate of humeral tuberosity or shaft fractures in patients with platform humeral stems converted to rTSA (9). A similar study of 26 patients with full modular stems likewise reported no intraoperative humeral complications (11).

Drawbacks of Humeral Platform System

Even convertible systems are not a guarantee to preserve the humeral stem. The initial position of the stem has to be accepted, which can be a
limitation, if the position is suboptimal (12). According to a study of Patel and Co-workers in 79% the modular stems have to be revised and only 21% of the stem implants could have been converted to rTSA (13). Wieser et al. (14) found that from 45 modular stems which have to be revised only 28% of the stems were converted to rTSA, whereas 72% of the humeral stems were removed. On the contrary in a small series of only 15 shoulders all humeral stems and glenoid baseplates were found to be well-fixed and could be retained (15). If the primary modular stem was implanted too high or due to a long standing upward migration of the humeral implant it could be impossible to reduce the rTSA. The convertibility of a modular humeral platform system seems to depend on the constructive design of the modular parts. In a radiographic study the implantation of six different reverse systems were simulated using the stem in the same position. The lengthening differed from 11mm to 33 mm and the largest offset-deviation was calculated with 21,7 mm and the smallest with1.5mm (16). The modular epiphyseal device for changing to inverse is in some cases too bulky.

Metal-back Glenoid Component in a Platform System

A platform system utilizes a versatile metal-backed glenoid that allows simple exchange of the polyethylene component when revising
aTSA, or conversion to a glenosphere when converting from aTSA to rTSA (17). Glenoid component loosening represents 25 % of all complications related to aTSA (18). Often, glenoid component loosening is combined with a rotator cuff tear, glenohumeral instability or component malposition [19].
Convertible glenoid systems of the latest generation are based on the experience gained with the anchorage technique for the glenospheres in rTSA. The modern convertible glenoid implants provide a much higher anchoring stability than the non-convertible metal backed glenoid components of the first generation.
The metal backed systems of the first generation were developed in the late 80s and early 90s of the last century and showed serious conceptual errors (20,21,22,23,24). The metal backed trays were either to high or too thin, sometimes not stable enough. The anchoring mechanism in the bone consisted of a keel, non cylindric cone, expansion dowel, hollow screw, with mostly too weak pegs or additional screws which were arranged only in a vertical row. These anchorage techniques were not able to withstand the shear forces that occurred, resulting in micro instability and/or fatigue fracture.
These problems were compounded by failure of the capture mechanism of the PE inlays from the tray, by the known polyethylene wear and by overstuffing of the rotator cuff due to too much lateralization by the height of the glenoid implant. Therefore, the failure and revision rate of the metal backed components was significantly higher than that of the cemented PE implants (25).
The new generation of convertible metal backed trays feature a highly stable anchorage mechanism of the metal carrier in the glenoidal vault as a significant design improvement. The convertible glenoid implant developed by Kany and Valenti (FH Orthopedics ,France) offers a monoblock keel system, which can be secured by an transglenoidal locking screw that secures the keel against both cortices of the glenoidal vault. For revision surgery, when an iliac crest bone graft is necessary, a special long-peg metal back component is also available (4).
Castagna developed a monoblock system (Lima Corp.,Italy) with a central hollow peg with external thread, which is driven into the glenoid floor press fit and which allows the bone to grow in (11).
The convertible metal backed glenoid developed by Habermeyer in cooperation with Arthrex Inc. has been in clinical use since 2011. The Universal GlenoidTM component consists of a titanium monoblock baseplate with a 4 mm thickness. The backside has a two-stage flat back design with a 200 micrometer titanium plasma-sprayed (TPS) and a 20 micrometer Bonit CaP coating for bone in- and ongrowth. The two stage flat back design strongly embodies the metal back by increasing the contact area and therefore preventing the rocking horse effect. The baseplate with a cone shaped cannulated central post is fixed by using a central 6.5mm compression screw through the cannulated post engaging the contralateral cortex of the glenoid vault. The central screw offers ten times more compression and 2.3 times more shear strength than baseplates with a central peg alone. Peripheral 4.5mm locking screws secure against hoop tension and rotation of the baseplate. The UHMWPE liner has a thickness of 2.5mm at the bottom and 4.5mm at the edge, a „Plus" version owns a thickness of 3.5mm and 5.5mm for soft tissue balancing. The UHMWPE polyethylene inlay is fixed to the metal back component by a cone like central peg and 4 peripheral central pegs providing a stable fixation with the metal backing. The glenoid implant has a pear shaped design and comes in three different sizes (s,m,l).
In case of converting the anatomic glenoid implant into a reverse system, the PE liner is disconnected and a glenosphere with a cone is tapped into the metal-back baseplate.

Results of convertible metal-backed Glenoid Components
Kany(4) et al. recently reported their experience with a platform shoulder arthroplasty system in 29 patients with a mean follow up of 28 months. Only two metal-backed glenoid components required exchange during conversion from aTSA to rTSA, both due to loosening in the setting of Walch type B2 glenoid bone wear. At a mean follow-up of 28 months no radiological glenoid or stem loosening was noted.
Castana(11) reviewed 26 patients operated for revision to an rTSA from
an original implant (hemiarthroplasty or aTSA) with an SMR
modular system (LimaCorp.) at a mean follow up of 32 months. Radiography obtained after revision showed no radiolucency around the humeral stems or glenoid. The CT scan showed good integration and no signs of loosening.
Habermeyerat al.(26) presented prospective midterm results (43months) of a new convertible glenoid component in 66 cases. Radiologically, a incomplete radiolucent line ≤ 1mm was seen in 5,3% and ≤ 2mm in 3.6%. No loosening, no shift in position or PE wear was found. All the cases have been centered at the axillary view. As a glenoid specific complication, two cases of PE-dissociation both with a Walch Type 2 glenoid were seen. The first case was combined with a RC deficiency 43 month postoperatively, with revision to rTSA and the second after lifting a heavy load at 26 months postoperatively, that could be revised with a PE-replacement. A significant improvement of overall Constant Score from 37 to 75 points and also an improvement of all its subcategories could be shown.

CONCLUSION

When implanting anatomical hemi- or total prostheses, the concept of convertibility can no longer be ignored, as the revision of the prosthesis is associated with a lower complication rate, both humeral and glenoid sided, allowing a gentler surgical technique. Even though the shafts are not always truly convertible - for anatomical or implant-specific reasons - the convertible metal-backed glenoid components are almost always easy to change. Therefore, the new convertible glenoid components might the implant of the future for chronic decentered glenoid defects (type B1 -B3) and critical rotator cuff conditions.

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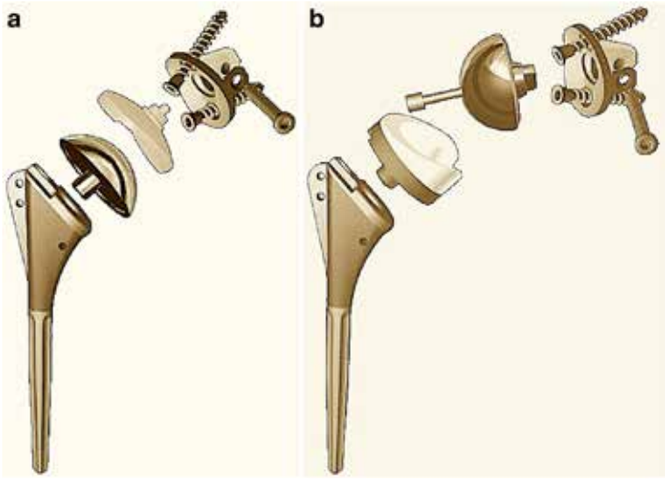

Figure 1
Convertible Stem Prosthesis with Convertible Glenoid (FH Orthopedics, France)

Figure 2
Fully Convertible Platform System (Lima Corp.,Italy)

Figure 3
Convertible Anatomic and Reverse Glenoid Component (Arthrex Inc.,USA)

29/ UNSTABLE ATSA: HOW TO MANAGE

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INTRODUCTION

One of the most commonly addressed complications of anatomic total shoulder arthroplasty (ATSA) is instability. The prevalence of which ranged from 0 to 18.2% in patients where an unconstrained implant had been used[5]. More recently in a large cohort series Wirth and Rockwood reported that horizontal instability occurred in 5.2% of 1,496 total shoulders[32]. With unconstrained shoulder prosthesis, instability can occur in any directions or combination of directions and it can be early or late after the procedure. It is rarely the result of a serious traumatic event. Whereas this instability can occur in any directions, the commonly described causes are quite specific. These typically include incorrect component positioning in terms of height and/or version at the time of surgery, improper component sizing, soft-tissue imbalance, neurological damage and implant loosening[14, 19, 22, 33].
In such a situation, specific revision procedures can be proposed depending on the causes of the prosthetic instability such as re-positioning or re-sizing the component, bone block procedures, soft-tissue repairs with variable and unpredictable results [14, 19, 24, 33]. Another option is the conversion from an anatomical to a reverse arthroplasty, especially when there is a rupture of the subscapularis along with postero-superior cuff tear. This situation can lead to an antero-superior escape of humeral head, which is truly a devastating complication. Since 2003, we have been using a completely convertible shoulder platform system with the advantage of easier and less cumbersome revisions. This system has a universal humeral stem with metal backed (MB) and cemented (CG) options for the glenoid implant. During conversion to a reverse prosthesis, the surgeon can remove the humeral head and implant a metallic tray with a polyethylene bearing without removing the humeral stem. If the glenoid implant is a non-cemented MB device, the conversion is easier allowing removing only the polyethylene shell leaving the well-fixed glenoid baseplate, which will support the glenosphere. A good understanding of the causes for instability after shoulder arthroplasty is essential to prevent such complications at the time of surgery and to efficiently manage the problem if it does occur postoperatively. The results, advantages and complications of such a completely convertible shoulder system are reported in only a few papers [4, 15].
The main purpose of this study is to review our cases of instability following anatomic shoulder prosthesis to identify its potential predictors. The secondary purpose was to report the clinical and radiological results of our revision procedures in a retrospective study of twenty-seven cases.

MATERIALS AND METHODS

Between 2003 and 2013, 546 primary anatomical shoulder arthroplasties were performed by the three senior surgeons of our group (Denis Katz, Jean Kany and Philippe Valenti) at three different institutions (Refer Table 1). There were 273 ATSAs with ingrowth metal-backed glenoid components (ATSAMB), 156 ATSAs with cemented glenoid components (ATSACG) and 117 hemiarthroplasties (HA).
- Fourteen patients who were lost to follow-up within three months were excluded from the study. Hence, the total number of patients amounted to 532.
- Inclusion criteria: We retrospectively analyzed all patients who had a postoperative instability of their shoulders after an anatomic shoulder arthroplasty performed during this period of time.
- Exclusion criteria: The patients who developed instability following trauma on the operated shoulder or nerve damage unrelated to the surgical procedure were excluded. Any shoulder with a confirmed infection identified at any point of time - either preoperatively or intraoperatively - was excluded. According to each of our infection departments, a minimum of five cultures in each revision case was performed in order to rule out a possible low-grade infection. All cultures at our institutions were held for fourteen days to assess for Cutibacterium acnes.
Twenty-seven patients (21 women, 6 men) were diagnosed with a postoperative instability, which represents 5.07% of the cohort. Mean age of the patients at the time of the index surgery was 66.3 years (range 42-83). The indications were malunion following a proximal humeral fracture (two), primary osteoarthritis (OA) of the shoulder (thirteen), post traumatic osteoarthritis (two), OA following recurrent anterior dislocation of the shoulder (six), acute four-part proximal humeral fractures (three) and posterior instability following an open Latarjet procedure (one). The right shoulder was implicated in twenty-two cases and the dominant side in twenty-six.

Prior surgery (index procedure) (Refer Table 2)

No patients had any prior surgeries in the shoulder at the time of the index procedure except one patient for Latarjet procedure (traumatic anterior instability). All index procedures were performed in a semi-upright position or supine position with a sand bag below in the interscapular region. Interscalenic block followed by general anesthesia was the option for a better post-operative pain relief. A standard deltopectoral approach was used in every patient. A subscapularis peel was performed in each case (except for the four trauma cases), in order to allow medial translation of the transosseous reinsertion when passive external rotation was limited. The condition of rotator cuff at the time of the index surgery was normal or repairable according to clinical, radiological and per-operative data. A tenodesis of the long head of the biceps into its groove was performed in every case. Fourteen patients underwent ATSAMB, five ATSACG and eight HA. All the patients had an Arrow Universal Shoulder Prosthesis platform system (Arrow, FH Orthopedics, Mulhouse, France).

After humeral preparation, the trial stem was placed to protect the humeral cut while preparing the glenoid. The glenoid side was exposed with a capsular release and clearing of the labrum. Great care was taken to visualize the limits of the glenoid vault as preoperative CT scan could evaluate osteophytes and glenoid version. The ancillary system allowed accurate reaming and preparation of the glenoid for a press-fit keel groove to ensure a perfect contact between the glenoid component and the bone. Special attention was paid to find the perpendicular glenoid vault axis. In case of glenoid dysplasia type B or C according to Walch classification30, the correction of the glenoid retroversion was attempted to recreate the native glenoid version. An asymmetric anterior reaming was performed alone when there was no risk of severe compromise in the healthy bone volume. On the contrary a combination of anterior reaming and posterior bone graft was performed. The cancellous bone grafts from the humeral head were placed posteriorly onto the micro-perforated underlying glenoid bone. In this latter situation a MB glenoid component was preferred to a CG one's to prevent possible risk of thermal necrosis of the grafts during cement setting. No compensatory anteversion of the humeral component was performed to prevent any posterior instability. The MB glenoid component thickness was 6.5 mm, 3.5 mm for the PE and 3 mm for the metal tray. The deep convex surface and the keel was hydroxyapatite coated. The primary fixation was ensured by two (diameter 5.5 mm) cancellous screws axially and could be enhanced by a third sagittal screw. We had nine type A1, six A2, one B1, seven B2 and two C glenoid according to the Walch classification 30 and there were two anterior glenoid bone loss in chronic and locked anterior dislocations. In six B2 and two C cases (30%), severe glenoid erosion existed and cancellous bone graft was added under the MB glenoid baseplate.

The humeral stems were press-fit in twenty-one shoulders (77%) and bone from the humeral head was grafted into the medial part of metaphysis to avoid varus deviation of the stem. In the remaining six cases, the metaphyseal bone was osteoporotic (or fractured) which made the humeral stem to be cemented. The humeral component was always implanted in 20° of retroversion, irrespective of the type of glenoid dysplasia. Careful transosseous repair of the subscapularis was performed in all cases.

Timing of instability (Refer Table 2)

The mean interval between the index procedure and the treatment for instability was 13.26 months (range 1-120 months). The time duration of instability was grouped as immediate when dislocation or subluxation occurred within 1 month following the index surgery (twelve patients). Eight patients were "early dislocators" (when dislocation occurred between one month and six months). Five patients were named "late dislocators " (when dislocation occurred between six months and two years). Any dislocations occurring at or after two years were grouped as very late dislocators (two patients).

Revision surgery for instability (Refer Table 2)

All revisions were performed through the previous deltopectoral approach in the beach chair position under general anesthesia with an interscalenic block. We used a deltopectoral approach in every case to allow distal extension of the exposure in case of stem replacement. Adhesions at the deep part of the deltoid and the conjoint tendon were carefully released. The intact subscapularis tendon was peeled off from the medial border of the bicipital groove in order to obtain sufficient length for a tension-free reinsertion. In this situation the version/height of the stem and of the glenoid component were analyzed to identify a possible malpositioning and were corrected when needed. The quality of the fixation of the glenoid baseplate and the humeral stem were systematically evaluated. The subscapularis tendon was medialized and reinserted transosseously. When a subscapularis and/or the supraspinatus muscle tear was the cause for instability a conversion from an anatomic to a reverse shoulder arthroplasty was performed.

Etiology of instability: Operative data (Refer Table 2)

The cause for instability was identified as subscapularis rupture in ten patients (torn and retracted at the level of the glenoid or impossible to identify to allow its reinsertion). A massive rotator cuff tear was found in six patients (fig 1).

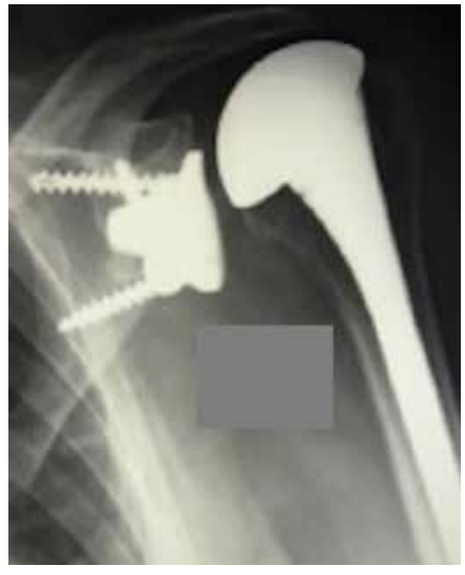

Figure 1
Superior dislocation caused by a late massive cuff tear (Subscapularis and Supraspinatus). This situation is the main cause of ATSA instability in our experience

A malpositioning of the components was the cause in eight patients (incorrect version of both components in two, glenoid malpositioning in five (fig 2) and humeral malpositioning in one).

Figure 2
Posterior ATSAMB dislocation after B2 glenoid reconstruction. With surgical experience and optimized preoperative planification, this cause tends to disapear

In one case a MB glenoid loosening was responsible for instability (sustaining a per-operative fracture at the time of the index surgery). There was polyethylene (PE) dissociation from MB in one case, and an excessive shortening of humerus in one (fig 3).

Figure 3
Inferior HA dislocation caused by a technical mistake (too distal stem implantation). Technical error implantation is the second cause of ATSA instability after soft tissue deficiency in our experience

The direction of instability was identified as ten anterior, nine superior, one inferior and seven posterior. There was one transient and immediate post-operative axillary nerve injury. Twenty cases were classified as immediate or early dislocations: eight with a rupture of the subscapularis tendon, eight with an error in the implant orientation, one with a PE/MB dissociation, one with a MB loosening (peroperative glenoid fracture at the index surgery), one with a transient nerve palsy and one with a humeral shortening. Five cases were classified as "late dislocations" and were all related to a massive rotator cuff tear.

Prosthetic component

The Arrow convertible system is a platform system whereby the humeral stem and the glenoid MB baseplate are the same regardless the type of arthroplasty. During conversion the anatomical head of the humeral implant was disconnected from the stem and removed. A circumferential capsular release was systematically carried out. In case of MB glenoid component, the PE glenoid onlay was then unlocked from the baseplate. In case of CG component, it was switched for a MB glenoid component. In this latter challenging situation with severe glenoid bone loss, an iliac crest cancellous bone graft along with a long peg MB component was implanted. A glenosphere was impacted on the baseplate and a PE humeral bearing was

then implanted on the humeral stem. Intraoperative stability of the implant was assessed looking for any posterior, anterior or inferior impingement.

Treatment of instability (Refer Table 2)

Of the twenty-seven patients identified with instability, two patients were reduced successfully without surgical intervention. One of these patients who had undergone successful closed reduction dislocated at the early post-operative period due to transient axillary nerve palsy. He required a conversion at a later date for recurrent instability due to an associated glenoid component malpositioning. The remaining one had dislocation 81 months post-operatively with a massive rotator cuff tear. In six patients specific revision procedures were performed which included two bone blocks, two cemented glenoid component repositioning, one humeral stem re-cementing (wrong version) and one subscapularis tendon repair. Eighteen cases needed a conversion to a reverse shoulder arthroplasty (RSA). In two out of those eighteen conversions (11.1%), reduction of the RSA was either impossible or considered to be too tight even after extensive soft-tissue release and resection of the remaining supraspinatus and hence the stems (one cemented and one uncemented) had to be replaced in a lower position by minimal humeral shortening to allow reduction. For the cemented stem a humeral osteotomy was mandatory for implant removal and a new-cemented stem was implanted in accurate position after reconstruction of the humerus using cerclage wiring. For the uncemented stem, removal was possible without osteotomy and hence replaced with a new-uncemented stem in the accurate position. In two cases no treatment was given due to high risk of anesthesia.

Post-operative management.

All the patients were admitted at the hospital on the previous day of surgery and were discharged two days after surgery if medically fit. No physical therapy was made in the postoperative days in the hospital in order to prevent an immediate postoperative dislocation. A sling was given for four weeks postoperatively and an outpatient physical therapy was started as the protocol (Kany platform system). A systematic double antibiotic therapy was set up which was stopped when culture was negative in more than three samples taken or modified according to the results.

Clinical evaluation

Patients were evaluated postoperatively (at three weeks, three months, six months and one year interval). Clinical evaluation included pain scores (visual analog scale), function, range of motion (ROM) and strength, which were assessed by the senior authors and were rated according to the Constant score 6, the SSV (Simple Shoulder Value) 17 and the SST (Simple Shoulder Value) 10. Pre- and postoperative values were then compared. Shoulder stability was also evaluated. Patient satisfaction was graded subjectively according to a four point rating scale as much better (4), better (3), same (2) and worse (1).

Radiological evaluation

The patients were evaluated postoperatively with X-rays of the shoulder during those visits. A standard AP-view with neutral, internal, and external rotation and an axillary lateral view were routinely taken to evaluate component migration or subsidence. In TSA and HA superior translation was evaluated in AP view in neutral. Anterior and posterior migrations were similarly evaluated in axillary lateral view. Component loosening was identified according to the radiolucencies around the glenoid and humeral components 26,27. In RSA, radiographs were evaluated with special reference to scapular notching and fractures of the acromion or spine of the scapula.

RESULTS

Clinical outcomes

The mean duration of follow-up between the revision procedure for instability and the most recent clinical follow-up was thirty-seven months (range, 12 to 132 months). Two patients were lost to follow-up (twelve months and thirty six months respectively) after the revision surgery without any recurrence of prosthesis instability at the last follow-up. Two patients died unrelated to surgery (34 and 36 months respectively after the revision surgery with no recurrence of the instability).

Active range of motion was significantly improved. Active flexion increased significantly from a mean 82 (range; 30°/150°) to 108° (range; 10°/170°). Active external rotation with the elbow on the side increased significantly from 13° (range; -10°/60°) to 29° (range; -10°/70°) and with the arm held in 90° of abduction from 30° (range; 0°-20°) to 45° (range; 0°/90°). Mean pain scores improved from three points to twelve. VAS improved significantly from six to two. The mean Constant Score improved from twenty-six pts (range; 2-50) to fifty-one pts (range; 20-90). The mean SSV improved from 25% (range 10-50) to 52% (range; 25-85). The mean final SST was six "yes" (Refer Table 3).

Subjectively ten patients rated their shoulders as much better, ten better and seven same as preoperatively. Out of these seven patients who rated their shoulder as "same", two had conversion, one had bone block procedure and one had closed reduction. The remaining two could not undergo surgery due to high risk for anesthesia. None of them rated their shoulder worse.

Radiological outcomes

No periprosthetic lucency or shift in component was observed at the last follow-up. There was no scapular notching. No fracture of the acromion or the scapular spine was observed in case of conversion.

Complications

One patient, in whom the HA was converted to a RSA after a failed closed reduction, dislocated it again two years later because of a shortening of the humerus. A second revision was successful with a thicker cup humeral component. Except this case no patients had instability or infection and none of the twenty-seven shoulders was categorized as failure.

ANALYSIS OF THE RESULTS

In this study the global incidence of unconstrained convertible shoulder arthroplasty instability was 5.07%. This incidence was 5.24% for the ATSAMB, 3.35% for the ATSACG and 6.89% for the HA. Type B2 and C glenoid dysplasia were noted in 15.8% of HA, 6.3 % of ATSACG and 23% of ATSAMB during the index procedure.

- While analyzing the direction of instability in the ATSAMB group, we had five (35.71%) posterior instability, three (21.43%) anterior instabilities and six (42.86%) superior instability. In this ATSAMB group 64.3 % (nine cases) of instabilities were due to soft-tissues failure and 35.7% (five cases) were due to glenoid component malpositioning knowing that all those patients had either Walch type B2 or C glenoid.
- In the ATSACG group we had two (40%) anterior instability, two (40%) posterior instability and one (20%) superior instability and in this group there was one type B1 dysplastic glenoid.
- In HA group we had five (55.6%) anterior instabilities, three (33.3%) superior instabilities and one (11.1%) inferior instability. In this HA group two patients (22.2%) had anterior glenoid bone loss along with massive rotator cuff tear in one and subscapularis tendon tear in the other leading to anterior instability. In the remaining six patients, three (33.3%) had massive RCT, one (11.1 %) had subscapularis tendon tear and two (22.2%) had humeral component malposition/shortening.

The percentage of patients with soft tissue imbalance was 16/27 cases (59.3%) (Table 4).

With a significance level set at 0.05, a P value of less than 0.05 obtained with this test for all the parameters except the ER2 indicates that the surgical procedure significantly enhanced the functional outcomes of all the patients (Table 3).

The final Constant score was compared in the patients with a conversion procedure and in patients with specific procedures. While both groups significantly improved as compared to their initial assessments, subgroup analysis of the scores revealed that the conversion group did have a better outcome (Pre-op 25.9±8.8 versus 56.7±13.1 at follow-up) which was statistically significant (p=0.001) as compared to the patients who underwent other procedures (Pre-op 27.0±8.0 versus 38.7±28.8 at follow-up, P=0.065). Direct comparison of the constant scores at the follow-up did reveal a clinically significant difference between the groups (Conversion 56.7±13.1 versus Other procedures 38.7±28.8), although the mean difference was not statistically significant (p=0.109) (Table 5).

DISCUSSION

Within a ten-year period, since 2003, we reported 5.07% postoperative anatomic convertible shoulder prosthesis instability out of 546 cases. This is similar to the Wirth and Rockwood report32.

Anterior shoulder prosthetic instability has most often been attributed to disruption of the repaired subscapularis tendon 19 and has been linked to inferior outcomes 3,13,18,23. Options to deal with the subscapularis tendon during the primary procedure include plain tenotomy, subscapularis tendon peeling and lesser tuberosity osteotomy (LTO) 9. During index surgery subscapularis muscle peeling was made in 27/27 cases. Nevertheless the most frequently identified cause for instability in our study was subscapularis tendon rupture (10/27). What's more, six patients were found to have a massive rotator cuff tear at the time of the revision surgery. One argument is that a glenoid metal-backed component (which is thicker than a cemented glenoid component) could lead to subscapularis and/or massive rotator cuff tendon rupture and consequently to anterior instability or to a devastating anterior-superior escape of the humeral head 31. Our incidence of instability was actually higher for the ATSAMB (5.24%) than for the ATSACG (3.35%). However we reported B2 and C glenoid dysplasia in only 6.3 % of ATSACG but in 23% of ATSAMB during the index procedure as we preferred MB for posterior glenoid reconstruction. Type B2 and C glenoid dysplasia - which is one of the major causes for post-operative instability 11,21 - is not rare in patients with shoulder osteoarthritis and represents 24-32.5% patients 12,30. That is the reason why soft-tissue failure in our study may be due to overstraining of the soft tissue during correction of posterior dysplasia in four out of nine cases (44.4 %) (not because of the thickness of the MB that is only 3mm thicker than the CG). Those results highlight the fact that the amount of bone block to be placed in order to prevent a posterior instability from happening has to be quantified. Inability to correct posterior glenoid Walch B2 or C deformities with regular cemented glenoid components has been associated with high rate of loosening whichever be the technique used:

either augmentation with polymethylmetacrylate cement to fill the posterior defect or bone grafting which may lead to thermal necrosis during cement setting 7.

Another shortcoming of ATSAMB described was its failure leading to instability through specific mechanisms like PE dissociation or catastrophic wear 1,2,29. Sanchez-Sotelo published five out of twelve shoulders with PE/MB dissociation 24. We do not confirm these data: in this study that includes twenty-seven cases of instability we describe only one case of PE/MB dissociation (3.7%) one month after the revision surgery which was a peroperative technical error. Moreover we came across five (1.8%) PE/MB dissociations in 273 ATSAMB implanted during the last ten years.

Although anteverting the humeral component to compensate for glenoid retroversion is relatively simple and has been advocated by many investigators 1,5,8 19,20,26,32 it does not increase the stability of a shoulder replacement with a retroverted glenoid component 12,25.

In patients with significant posterior glenoid bone loss, restoring a more neutral glenoid surface with a posterior bone graft and implanting a MB glenoid component was our technical option since 2003, although it was technically more demanding procedure16. This study described only four posterior instabilities correlated with a malpositioning MB component with type B1 (1 case) and B2 (three cases) glenoid dysplasia during our early days.

Soft-tissue imbalance is present in most cases of instability following shoulder arthroplasty, and component malpositioning plays an additional role in some cases. Sanchez-Sotelo showed that more than one half of the shoulders remained unstable despite attempts of revision 24. In our study all the shoulders were stable at the most recent follow-up. Eighteen patients (with the Arrow universal platform system) out of twenty-seven were treated by a conversion to a RSA with a final Constant score of 57. On the other hand nine patients who had specific open procedures such as bone blocks, humeral or glenoid component revision, subscapularis repair, reduction or nothing had a final Constant score of 39. This result could be explained by the fact that the universal Arrow platform system did not need either revision of both the stem and the glenoid base plate component to switch from a ATSA to a RSA (fifteen/seventeen cases) or soft-tissue repair.

Finally eleven unconstraint prostheses sustained episodes of prosthetic instability without any rotator cuff deficiency whereas sixteen unconstraint prostheses had either an isolated subscapularis tendon tear (ten) or a massive rotator cuff tear (six). Consequently, we do think that, soft-tissue deficiency was the main cause for unconstraint prosthesis instability instead of component malpositioning. This platform system with a cementless glenoid had the advantage of preservation of bone stock, reconstruction of glenoid bone loss if any and easier revision 15.

CONCLUSION

Soft-tissue deficiency was the main cause for our unconstraint convertible shoulder prosthesis instability, especially the subscapularis tendon deficiency, followed by the malpositioning of the glenoid component. As a clinical relevance the treatment led us most often to a conversion from a ATSA to a ARSA. As opposed to previous studies we had predictable and reliable results thanks to a platform system that made the revision easier.

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TABLES

	HA	ATSACG	ATSAMB	Total
Total number of patients	117	156	273	546
Patients lost to follow-up	1	7	6	14 (2.56%)
Remaining patients for the study	116	149	267	532
Number of patients with shoulder prosthesis instability	8 (6.89%)	5 (3.35%)	14 (5.24%)	27 (5.07%)
Glenoid Dysplasia (Type B, C or anterior defect)	4/8 (50%)	1/5 (20%)	9/14 (64%)	14/27 (51.8%)

HA : Hemiarthroplsaty ; ATSACG : Anatomic Total Shoulder Arthroplasty Cemented Glenoid ; ATSAMB : Anatomic Total Shoulder Arthroplasty Metal Backed

Table 1
Distribution of patients

Patient	Age	Sex	Walch Glenoid Type	Cause of instability	Direction of Instability	Timing of Dislocation (months)	Treatment	FU	Constant	SSV	SST	Subjective satisfaction
1	77	F	B1	Incorrect version H and G	Post	1	Conversion	16	59	60	8	Much better
2	81	F	B2	Sscp Rupture	Ant	18	Conversion	12	60	70	8	Much better
3	79	F	B2	Incorrect version H and G	Post	1	Conversion	12	68	70	8	Much better
4	76	F	B2	Sscp Rupture	Ant	3	Conversion	36	33	30	2	Same
5	83	F	B2	Sscp Rupture	Sup	22	Conversion	18	55	50	5	Better
6	45	F	A2	G loosening	Sup	1	Conversion	18	45	50	5	Better
7	69	F	B2	Sscp Rupture	Post	1	Conversion	60	73	75	10	Much better
8	63	F	C	Sscp Rupture	Post	1	Conversion	36	69	70	9	Much better
9	73	M	C	PE dissociation	Sup	1	Conversion	48	48	50	5	Better
10	42	M	A1	Incorrect version G	Ant	3	Conversion	16	65	65	8	Much better
11	64	M	B2	Axillary palsy Incorrect version G	Post	1	Reduction Conversion	34 (dced)	75	70	9	Much better
12	76	F	A2	Sscp Rupture	Ant	3	No surgery	18	32	30	2	Same
13	71	F	A2	Massive RCT	Post	84	Reduction	109	20	25	1	Same
14	65	F	A2	Sscp Rupture	Ant	1	Suture Sscp	132	42	40	4	Better
15	51	M	A2	Incorrect version G	Sup	3	G revision	39	90	85	12	Much better
16	65	F	A2	Malposition G	Sup	6	G revision	36 (lost)	45	45	4	Better
17	75	F	A1	Massive RCT	Sup	120	Conversion	24	25	30	2	Same
18	70	F	B2	Incorrect version G	Post	3	Conversion	37	57	60	8	Much better
19	60	F	A1	Massive RCT	Sup	24	Conversion	48	62	60	9	Better
20	73	F	A1	Massive RCT	Ant	1	No surgery	28	34	30	2	Same
21	73	F	AGBL	Sscp Rupture	Ant	1	Bone block	36 (dced)	21	25	10	Same
22	63	F	A1	Sscp Rupture	Ant	1	Bone Block	60	43	40	4	Better
23	65	F	A1	Incorrect version H	Ant	6	H revision	18	21	25	1	Same
24	59	F	A1	H Lenght	Inf	1	Conversion	20	62	60	8	Much better
25	53	F	AGBL	Sscp Rupture	Ant	3	Conversion	12 (lost)	46	50	5	Better
26	60	M	A1	Massive RCT	Sup	24	Conversion	60	55	50	7	Better
27	59	M	A1	Massive RCT	Sup	24	Conversion	18	65	65	8	Better

OA : (primary) OsteoArthritis
AGBL : Anterior Glenoid Bone Loss
LAD : Locked anterior dislocation
PTOA : Post Traumatic Osteo-arthritis
PL : Post Latarjet
ATSAMB : Anatomic Total Shoulder Arthroplasty Metal-Backed
ATSACG : Anatomic Total Shoulder Arthropasty Cemented Glenoid
Hemi : Hemiprosthesis
G revision : Glenoid component revision
H revision : Humerus component revision
SScp : Subscapularis
RCT : Rotator Cuff Tear
PE : Polyethylene

Table 2
Master table

Outcomes	Mean(SD)	95% CI	Significance (p value)
Pain (points)			
Pre-op	6.1(0.8)	5.8 to 6.5	
Follow-up	2.5(1.8)	1.9 to 1.9	0.001
AROM Flexion (degrees)			
Pre-op	82.2(28.3)	71.0 to 93.4	
Follow-up	105.7(39.7)	90.0 to 121.5	0.027
AROM Abduction (degrees)			
Pre-op	71.5(28.2)	60.3 to 82.6	
Follow-up	103.7(35.7)	88.6 to 118.4	0.003
AROM- ER1 (degrees)			
Pre-op	14.1(14.4)	8.4 to 19.8	
Follow-up	28.1(20.1)	20.2 to 36.2	0.007
AROM-ER2 (degrees)			
Pre-op	30.0(22.0)	21.3 to 38.7	
Follow-up	42.0(24.5)	32.4 to 51.7	0.083*
Constant Score (points)			
Pre-op	26.3(8.4)	22.9 to 29.6	
Follow-up	50.7(18.2)	43.5 to 57.9	0.001
SSV Score (%)			
Pre-op	24.6(7.8)	21.5 to 27.7	
Follow-up	51.1(17.5)	44.2 to 58.0	0.001

*Mean difference not statistically significant.
AROM : Active Range of Motion
SSV : Simple Shoulder Value

Table 3
Statistical Analysis of Outcome measures

Group (n=27)	TSA MB	TASC G	HA	Total
Soft tissue imbalance	6	4	6	16
Other causes	8	1	2	11
total	14	5	8	27
Percentage of patients with soft tissue imbalance	42.9%	80%	75%	**59.3**

Table 4
Distribution and percentage of soft tissue imbalances in patient groups

Surgical Procedure	Number of Cases	Constant Pre-op (Mean±SD)	Constant Follow-up (Mean±SD)	Significance over time	Significance between groups at Follow-up
Conversion	18	25.9±8.8	56.7±13.1	P=0.001	
Specific Procedure or Nothing	9	27.0±8.0	38.7±28.8	P=0.065*	P=0.109*

*Mean difference not statistically significant.

Table 5
Comparison of the final Constant score for the patients with a conversion procedure and others

PART 3

REVERSE SHOULDER ARTHROPLASTY: NEW TRENDS AND CONTROVERSIES PRESENTATIONS CLINICAL RESULTS

30/ BIOMECHANICAL PRINCIPLES IN REVERSE TOTAL SHOULDER ARTHROPLASTY

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BIOMECHANICS OF THE GRAMMONT PROSTHESIS

In 1985, Paul Grammont introduced the "Trompette" reverse prosthesis to maximize the deltoid abduction moment by medializing and lowering the center of rotator (COR) of the glenohumeral joint.[1,11] The reverse total shoulder arthroplasty (rTSA) design compensates for the lack of supraspinatus function in early abduction and increases deltoid efficiency over the range of motion.[24] Grammont's design philosophy has four key principles: (1) inherent stability; (2) medialized and distalized COR; (3) COR at or within the plane of the glenoid; and (4) large glenosphere and small humeral cup with an inclination of 155°.[3,7,11]

In contrast to native arthrokinematics, the semiconstrained design of rTSA prostheses fixes the COR, which converts distracting forces to angular rotation of the humeral head and to shear and compressive forces at the interface of the baseplate and scapula (Figure 1).[3,7]

To minimize shear forces and torque about the transverse glenosphere axis, Grammont medialized the COR by crafting the glenosphere as a hemisphere in opposition to previous designs which employed a larger, more lateralized sphere.[1]

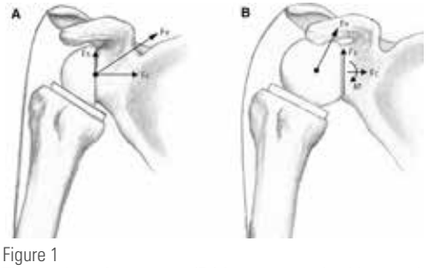

Figure 1
The resultant force vector (Fv) in a reverse shoulder prosthesis with medialized design (A) and lateralized glenosphere (B). (Fs = shear force, Fc = compressive force, M = moment arm) Scheme from Berliner et al., 2015.[3]

The medial shift of the COR has several important biomechanical consequences. Scapular notching has been observed in up to 96% of rTSA cases using a Grammont prosthesis.[1,17,33,35,37,40] In a biomechanical study, Gutiérrez et al. found that the adduction deficit was significantly greater for glenospheres with a smaller COR offset (Figure 2).[22]

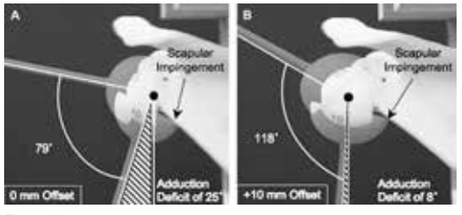

Figure 2
The adduction deficit is greater with a medialized COR (A) and smaller with a lateralized COR (B). Scheme from Gutiérrez et al., 2008.[22]

Loss of external rotation can cause significant disability following implantation of a Grammont-type prosthesis, in some cases requiring latissimus dorsi transfer with or without the teres major to restore functional capacity.[5,6,10,15,16] Several phenomena have been proposed to explain poor external rotation, including physical impingement, reduced posterior deltoid and rotator cuff tension, deficient teres minor function, and intraoperative damage to the suprascapular nerve (Figure 3).[7]

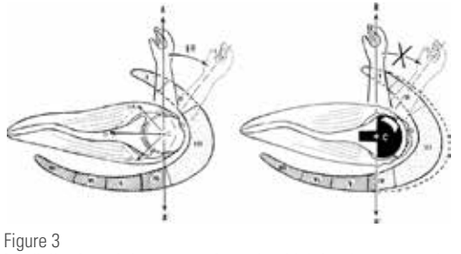

Figure 3
Medialization of the center of rotation (right) reduces posterior deltoid tension in external rotation. Slackening of the infraspinatus and teres minor may also contribute. Scheme from Boileau et al., 2005.[7]

Inappropriate deltoid tensioning may also cause undesired consequences.[7,24] Insufficient deltoid tension can lead to prosthetic instability by reducing intraarticular compressive forces. While some superior decoaptation is considered normal for the Grammont design, global decoaptation is an abnormal gap between the humeral cup and glenosphere that results from insufficient deltoid tension (Figure 4).[7] In contrast, excessive deltoid tension can lead to acromial stress fractures. Hypertensioning can also cause permanent, resting abduction and axillary nerve damage.

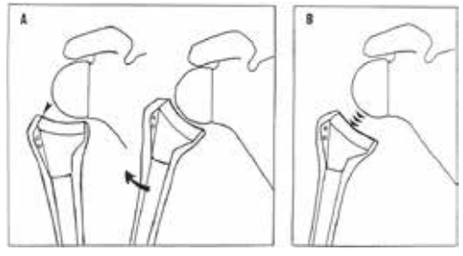

Figure 4
(A) Superior decoaptation resolves with abduction. (B) Global decoaptation results in glenohumeral instability. Scheme from Boileau et al., 2005.[7]

BIOMECHANICS OF THE 135° PROSTHESIS

In order to address concerns with scapular notching and impingement, Frankle et al. designed an implant with a 135° humeral neck-shaft angle.[1,2] This design implemented a more anatomic humeral inclination along with a more lateral COR and offset. Gutiérrez et al. found that the largest increase in impingement-free abduction occurred with a 10-mm offset and that the smallest adduction deficit occurred with a 130° humeral neck-shaft angle.[20] This was further confirmed by Werner et al. who found that 135° of humeral inclination enabled significantly greater external rotation and adduction compared to a 145° neck-shaft angle.[47] Oh et al. biomechanically examined various humeral inclinations and found that the 135° neck-shaft angle allowed for up to 12° of adduction before impingement occurred, as compared to the 155° implant that began to impinge at 2° of abduction.[37] Although decreasing the inclination has been shown to decrease adduction impingement angles, there is concern of implant loosening due to increased strain at the implant interface.[49] Lateralizing the center of rotation in implants with a 135° neck-shaft angle increases the moment at the interface between the glenoid bone stock and hardware causing greater component micromotion during dynamic loading.[49] This has been seen clinically with glenoid failure rates reported as high as 11%.[12,50]

A major concern of the 135° design is the biomechanical and stabilizing effects of the prosthesis.[37] Oh et al. found that although the 155° neck-shaft angle resulted in a greater risk of notching, it was significantly more stable to anterior dislocation forces compared to 135° neck-shaft humeral stems at 30° of internal rotation.[37] In comparison, the 155° neck-shaft humeral stem was found to be less stable in 30° of external rotation.[37]

In our own unpublished biomechanical analysis of the deltoid force requirements for rTSA prostheses with humeral inclinations of 135° or 155° degrees, we observed a lower combined deltoid force requirement for both inclinations compared to the native shoulder with a massive cuff tear (Figure 5).

The range of motion between both stem inclinations was not significantly different. Further biomechanical data are needed to truly determine how altering the humeral inclination alone changes the abduction moment arm, center of rotation, and glenoid-baseplate interface.

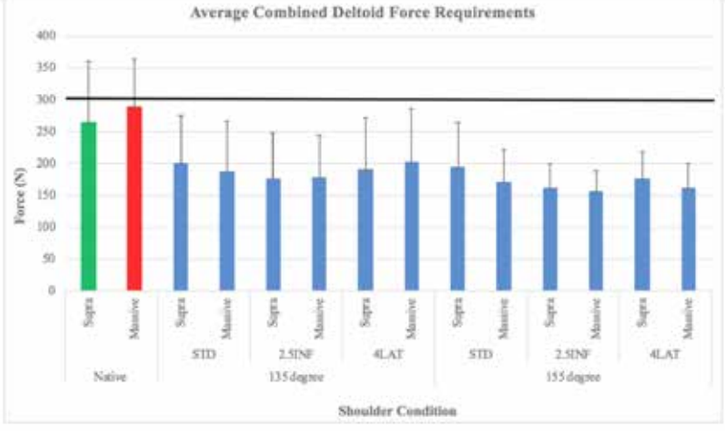

Figure 5
Combined deltoid force requirements for maximal abduction are reduced with 135° and 155° humeral stems compared to the native state. Tear classification: Supra = supraspinatus tear, Massive = massive tear. Glenosphere offsets: STD = standard, 2.5INF = 2.5 mm inferior, 4LAT = 4 mm lateral. (Joseph & Dyrna et al., unpublished)

SCAPULAR NOTCHING IN RTSA

Scapular notching is reported in up to 96% of rTSA cases and may lead to the development of bone loss, osteolysis, polyethylene wear, glenoid implant loosening and failure associated with poorer clinical outcomes.[1,17,33,35,37,40] Sirveaux et al. described a classification system including 4 grades of scapular notching (Figure 6).[14,44] Grade 1 and 2 may be attributed to a mechanical conflict.[14] In contrast, grades 3 and 4 may result from a biologic response to polyethylene wear and osteolysis.[14]

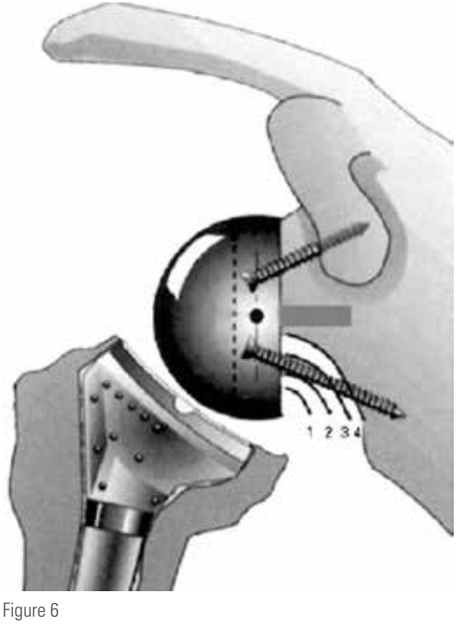

Figure 6
Grades of scapular notching according to Sirveaux et al.[44] Scheme from Levigne et al.[28]

Effect of glenosphere design on scapular notching
Eccentric positioning of the glenosphere to produce inferior overhang of the glenoid rim seems to ensure the greatest reduction in scapular notching.[21–23,36,39,41,43] A more lateralized COR approximates the physiologic condition and is known to decrease notching.[27] Glenospheres with a large diameter should be preferred to insure increased stability and impingement-free ROM as well as to decrease the risk of notching.[2,26,34,45]
Effect of humeral component design on scapular notching
With decreasing neck-shaft angle the humeral cup is positioned in more abduction relative to the humeral shaft.[14] This results in a more lateral offset and an improvement in impingement-free adduction.[26] Studies have shown that reducing the humeral neck-shaft angle decreases the adduction deficit.[20–22] However, a decreased neck-shaft angle also increases contact stresses. This may increase polyethylene wear, leading to glenoid osteolysis and scapular notching.[14]

STRESS FRACTURES OF THE SCAPULA FOLLOWING RTSA

Stress fractures in the acromion and scapular spine are less frequent, generally occurring 3 to 10 months after surgery in up to 10% of patients who underwent rTSA.[32,48] However, this incidence may be understated and may increase with more utilization of rTSA.[32,42] The pathology underlying stress fractures is continuous, starting with a stress reaction and progressing to nondisplaced fracture and then displaced fracture for which the rate of malunion or nonunion is up to 50% after nonoperative treatment.[32,38] Crosby et al. developed a classification based on fracture location in relation to the acromioclavicular joint.[8] Type I fractures are located in the anterior acromion, whereas type II fractures involve the acromial body posterior to the acromioclavicular joint.[8] Type III fractures include the scapular spine.[8] Levy et al. classified the fractures into subtypes using the location in relation to the deltoid origin (Figure 7).[30] Type I fractures represent involvement of a portion of the anterior and middle deltoid origin, Type II the entire middle deltoid origin and Type III the entire middle and posterior deltoid origin.[30]

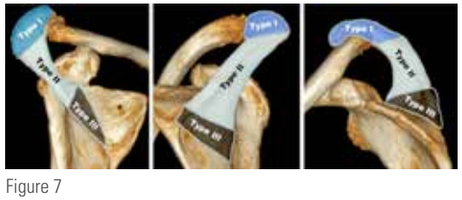

Figure 7
Classification of acromial stress fractures according to Levy et al.[30]

Stress fractures of the acromion and scapular spine may be a result of bony insufficiency secondary to patient and/or surgical factors.[32] The most significant clinical risk factor for stress fractures after rTSA is osteoporosis, which is present in 30.8% of fracture patients compared to 18.4% of control patients.[38] In addition, the biomechanical principles of rTSA, including a medialized and distalized center of rotation and greater deltoid tension secondary to arm lengthening, result in increased stress on the acromion, scapular spine and glenoid during shoulder motion.[32] Moreover, other intraoperative technical factors such as glenoid baseplate design, screw length, screw diameter and screw position have an effect on bone stress.[8,38] However, there are no clear recommendations regarding glenoid baseplate fixation so far.[8,38]
Wong et al. performed a finite element study evaluating the effect of humeral and glenoid implant position on acromial stresses in rTSA with 155° neck-shaft angle.[48] The highest acromial stresses were recorded in the region representing Levy type II fractures, where acromial fractures most commonly occur.[48] Inferior and medial positioning of the glenosphere significantly decreased acromial stress primarily due to increased deltoid mechanical advantage.[48] The greatest effect was reported in lower abduction angles.[48] However, further research is needed on the management of the various fracture subtypes.[32]

NEXT CHALLENGE: POSTERIOR GLENOID EROSION IN REVERSE SHOULDER ARTHROPLASTY

Severe glenoid erosion is encountered frequently in osteoarthritic patients and presents a challenge in reverse shoulder arthroplasty.[4,13,19,25] As reflected in the design of augmented implants, it has been assumed that bone loss in B2 glenoids is directed toward the 9 o'clock position.[25] However, recent literature suggests that the region of bone loss in osteoarthritic glenoids is posteroinferior rather than posterior.[4,25] Unfortunately, it remains uncertain if osteoarthritis results in altered kinematics and subluxation or if changed kinematics with subluxation leads to osteoarthritis.[25] Three erosion types in glenohumeral osteoarthritis were originally defined by Walch et al.[46] Favard et al. considered the progressive effect of humeral head migration resulting in a superiorly directed glenoid wear pattern (Figure 8).[9]

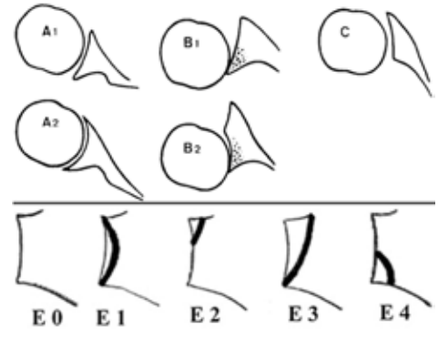

Figure 8
(Left) Osteoarthritic wear pattern according to Walch.[46]
(Right) Favard classification9 depicted with scheme from Lévigne et al.[29]

Advancements in three-dimensional reconstruction have allowed further analysis of glenoid erosion patterns originally classified in two dimensions by Walch and Favard.[9,46] This is needed since two-dimensional CT images inaccurately represent the wear pattern in osteoarthritic glenoids.[25] Knowles et al. confirmed the findings of Beuckelaers et al. that B2 glenoids show a wear pattern that is not axisymmetric to the superoinferior axis of the glenoid and that is orientated in the posteroinferior region (Figure 9).[4,25]

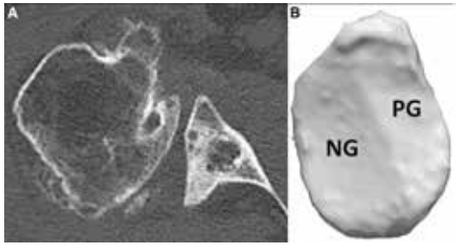

Figure 9
(A) CT scan of a B2 glenoid. (B) 3D reconstruction revealing the posteroinferior orientation of the erosion. NG = neoglenoid, PG = paleoglenoid. Scheme from Knowles et al.[25]

In our own unpublished 3D analysis from CT scans of B-type glenoids we observed 3 types of erosion (Figure 10A). We found posterosuperior (Figure 10B), posterocentral (Figure 10C), and posteroinferior (Figure 10D) glenoid wear.

Figure 10
(A) Classification of posterior glenoid wear pattern showing (B) posterosuperior, (C) posterocentral, and (D) posteroinferior erosion. (Otto et al., unpublished)

Martin et al. reported a bone loss of 50% at the superior glenoid and a significant reduction in the initial fixation strength of the baseplates.[31] Methods to correct glenoid retroversion in rTSA have been adapted from primary shoulder arthroplasty, including eccentric reaming of the anterior side.[13,18] The loss of valuable glenoid bone stock can cause reduced compressive strength of the remaining bone.[13] Furthermore, excessive prosthetic medialization can lead to instability.[19] While posterior bone grafting can be applied, this is technically demanding and the graft is subject to resorption and loosening over time.[13,18] All of this impacts long-term glenoid component fixation.[13]
Posteriorly augmented components may represent a future solution to correct excessive glenoid retroversion in rTSA.[13,18] Several advantages including reduced reaming, eliminated need for bone grafting, restored native joint line, and the conversion of shear forces to compressive forces at the glenoid neck.[13] Friedmann et al. observed that augmented baseplates with off-axis reaming can

maintain rTSA glenoid fixation, even in scapulae with very large posterior glenoid defects.[13] However, posterior glenoid erosion increased the baseplate displacement relative to a non-defect control, regardless of baseplate type or reaming method.[13] Higher glenoid wear was associated with greater increases in baseplate displacement.[13] The management of posterior glenoid erosion in reverse shoulder arthroplasty remains a challenge and further research on wear patterns as well as implant design is needed.

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31/ LATERALIZATION IN REVERSE SHOULDER ARTHROPLASTY: A DESCRIPTIVE ANALYSIS OF HUMERAL AND GLENOID LATERALIZATION

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INTRODUCTION

Since its first description by Grammont in 1985[1,2], reverse arthroplasty (RSA) has evolved, with now over 30 different designs of RSA commercially available. Grammont's design relied on 4 principles: (1) medialization of the joint center of rotation by medializing the glenoid and the humerus with a straight stem and a 155° neck-shaft angle (NSA) to increase the lever arm of the deltoid in active elevation and abduction; (2) positioning of the joint center of rotation at the bone-implant interface to reduce shear forces on the glenoid implant; (3) distalization of the humerus to retension deltoid fibers, and (4) a semi-constrained configuration to provide static stability and a stable fulcrum.

Gramont-style RSA has been reported to provide satisfactory results[3-5] but this design has been found to have several drawbacks. First, excessive medialization may lead to a slackening of any intact cuff, which could contribute to instability and weakness in external rotation. Second, the contour of the shoulder is somewhat altered[6,7]. Finally, the 155° NSA and glenoid medialization led to high rates of scapular notching[5,8] with the potential for polyethylene wear and glenoid loosening9.

Subsequent RSA designs tried to address some of these by providing a more lateralized reconstruction. Lateralization may be increased on the glenoid side at the scapular neck[10], baseplate[11] or glenosphere[12]. Modifications of the stem design have also been proposed: (i) a change in the NSA to 145 or 135 degrees to decrease scapular notching, (ii) curved and short stems to preserve bone stock, and (iii) onlay systems to facilitate conversion from an anatomic arthroplasty. These humeral changes translate into humeral lateralization, which introduces confounding factors when reporting results of lateralized RSAs.

The objective of this study was to provide a clear definition of lateralization (glenoid, humeral and global) and to measure and compare lateralization values provided by the most commonly used RSA implants currently available.

MATERIALS AND METHODS

RSA Designs included in the study

The templates of 22 different implants were obtained from manufacturers (Table 1). All templates were analyzed using SolidWorks 2017 SPO (Dassault Systèmes, Vélizy-Villacoublay, France). A total of 28 different configurations were included, as some implants allow different neck-shaft angles and/or the addition of a glenoid bone graft.

Definitions

Vertical lines were traced and used as a reference to measure lateral offset (LO) (Figure 1): line A is the vertical line passing through the middle of the humeral stem diaphysis; line B is the vertical line passing through the midpoint of the bearing of the humeral implant at the level of the humeral cut; line C is the vertical line passing through the "pivot point", defined as the deepest point of the articular surface of the humeral insert measured perpendicular to the surface of the humeral insert; line D is the vertical line passing through the center of rotation of the joint; line E is the vertical line passing through the medial most bone-glenoid baseplate interface. The horizontal distance between each of these lines was measured.

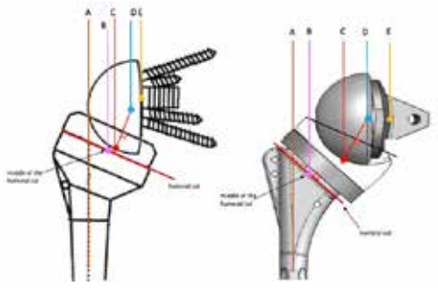

Figure 1
Templates of a medialized implant (Delta III (DePuy, Warsaw, IN)) and of a very highly lateralized implant (Arrow (FH Ortho, Heimsbrunn, France)
Line A is the vertical line passing through the middle of the diaphysis of the humeral stem
Line B is the horizontal line passing through the middle of the surface of the humeral implant at the level of the humeral cut
Line C is the vertical line passing through the "pivot point" defined as the deepest point of the articular surface of the humeral insert measured perpendicular to the surface of the humeral insert
Line D is the vertical line passing through the center of rotation of the joint
Line E is the vertical line passing through the bone-glenoid baseplate interface.
Humeral lateral offset (distance AC) was defined as the sum of the humeral stem offset (distance AB) and of the humeral insert offset (distance BC).
Glenoid lateral offset (distance CE) was defined as the sum of the "perceived radius of the glenosphere" (distance CD) and of the center of rotation offset (distance DE).
Global lateral offset (distance AE) was defined as the sum of the glenoid lateral offset and of the humeral lateral offset.

Humeral LO (AC) was defined as the sum of the humeral stem and humeral insert offsets (AB + BC). Glenoid LO (CE) was defined as the sum of the "perceived radius of the glenosphere" (CD) and of the center of rotation offset (DE). Global LO (AE) was defined as the sum of the glenoid and humeral lateral offsets. Finally, Greater Tuberosity LO was defined as the distance between the medial most bone-glenoid baseplate interface and the greater tuberosity (Figure 2)

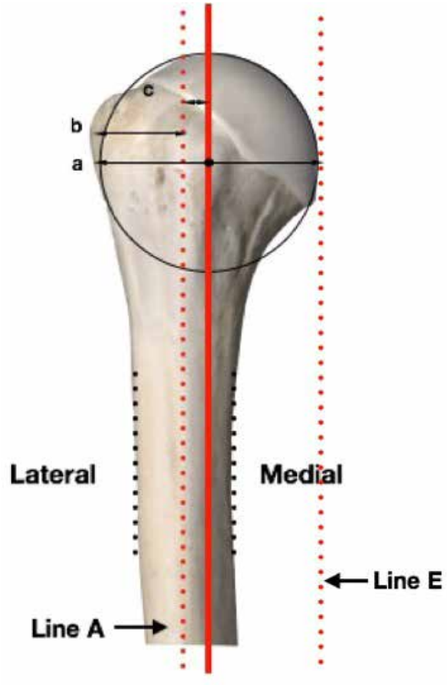

Figure 2
The diameter of the humeral head (a) represents the distance between the glenoid (line E) and the greater tuberosity (mean overall greater tuberosity lateral offset). The humeral head has a medial offset (c) relative to the diaphyseal axis (line A) of a mean 6.9 mm. The distance between the diaphyseal axis and the greater tuberosity (b) which is equal to the radius of the humeral head minus the medial offset of the center of rotation of the humeral head.

The design of the of the original Grammont design (Delta III; DePuy, Warsaw, IN) was used to normalize all measurements. The relative lateralization of the implants was calculated as the difference between the LO of each particular implant and the LO of the Delta III. Implants were then classified into categories based on a classification introduced by Hamilton et al.16 modified for this article.

Glenoid Lateralization
- medialized glenoid (MG): glenoid LO (CE) < 5 mm of Delta III
- lateralized glenoid (LG): glenoid LO (CE) 5 mm of Delta III.

Humeral Lateralization
- medialized humerus (MH): humeral LO (AC) < 5 mm of Delta III.
- minimally lateralized humerus (LH): humeral LO (AC) 5 – 9 mm of Delta III.
- lateralized humerus (LH+): humeral LO (AC) 10 – 14 mm of Delta III.

Global Implant Lateralization
Each implant was therefore defined as a combination of one of two glenoid categories and one of four humeral categories: MGMH, MGLH, MGLH+, MGLH++, LGMH, LGLH, LGLH+, LGLH++. However, as this classification does not give any information on the amount of global lateralization, an additional classification was created to separate implants in categories of 5 mm increments according to the value of global LO (AE) in reference to Delta III:
- medialized RSA (M-RSA): < 5 mm
- minimally lateralized RSA (ML-RSA): 5 – 9 mm
- lateralized RSA (L-RSA): 10 – 14 mm
- highly lateralized RSA (HL-RSA): 15 – 19 mm
- very highly lateralized RSA (VHL-RSA): > 20 mm

Overall Medialization of the Greater Tuberosity LO (Figure 2)
The diameter of the humeral head represents the distance between the glenoid (line E) and the greater tuberosity and represents the native greater tuberosity LO. As we used templates, direct measurement of the overall offset of the greater tuberosity after implantation of the different RSAs could not be measured directly but had to be calculated. The humeral head has a medial offset relative to the diaphyseal axis (line A) of a mean 6.9 mm. and the mean diameter of a humeral head is 46.2 mm 23. Thus, the distance between the diaphyseal axis and the greater tuberosity is equal to the radius of the humeral head minus the medial offset of the center of rotation of the humeral head: (46.2 / 2) – 6.9 = 16.2 mm (Figure 2). The mean greater tuberosity LO was considered to be the global LO + 16.2 mm.

Measurements
For each implant, LOs were measured using the smallest available baseplate, a 36mm glenosphere, and the thinnest polyethylene humeral insert. In addition, the maximal possible LO was also measured for each implant (with the largest and/or more lateralized glenosphere, and the most lateralizing humeral insert). The difference between the maximal LO and the baseline one indicates the range of LO allowed by each implant.

RESULTS

Overall results are detailed in table 1.

Global Lateralization (Refer Table 2)
The global LO of the Delta III is 13.1 mm. There were 5 M-RSA implants (LO < 18.1 mm), 5 ML-RSA (LO 18.1 - 23.1 mm), 7 L-RSA (LO 23.1 - 28.1 mm), 6 HL-RSA (LO 28.1 - 33.1 mm), and 1 VHL-RSA implants (LO 33.1 - 38.1 mm). The average range of LO is 10.8 mm. The range of global LO that is possible to obtain with one given implant varies from 3.3 mm to 20.9 mm (Table 1).

Glenoid Lateralization (Refer Table 3)
The glenoid LO of the Delta III is 9.6 mm. MG implants had less than 14.6 mm of glenoid LO; LG implants had a glenoid LO 14.6 mm. Eight implants lateralize on the through the glenosphere, baseplate or both.

Glenosphere Lateralization
The glenosphere LO of the Delta III is 7.6 mm. Four implants lateralized through the glenosphere (glenosphere LO greater than that of the Delta III + 5 mm (7.6 mm + 5 mm = 12.6 mm).

Influence of the size of the glenosphere (Table 4)
An increase of the size of the glenosphere from a 36 mm to the next size available (39/40/41/42 or 44 mm) leads to a mean glenoid lateralization of 1.14 (range; -1.1; 2.3) mm and a mean global lateralization of 1.44 (range; -0.4; 4.3) mm.

Baseplate Lateralization
The baseplate LO of the Delta III is 2 mm. Three implants lateralize through the baseplate (baseplate LO greater than that of the Delta III + 5 mm (i.e. 2 mm + 5 mm = 7 mm).

Humeral Lateralization (Refer Table 5)
The humeral LO of the Delta III is 3.5 mm. Nine implants were MH (humeral LO < 8.5 mm), seven were LH (humeral LO 8.5 - 13.5 mm, and 7 were LH+ (humeral LO 13.5 - 18.5 mm). Humeral lateralization is influenced by stem design, NSA and onlay versus inlay design. The mean NSA of implants that do not lateralize on the humeral side is 149.1° (range; 135°-155°) versus 133.6° (range; 127.5°-135°) for those that do. All LH+ implants have an onlay design, versus only 13% of the MH and LH implants. Mean insert lateralization is + 11 mm (range; 7.3 mm – 17.7 mm) in onlay implants, versus + 2.22 mm (range; -1.9 mm – 5.5 mm) in inlay implants. The offset of the the Delta III humeral insert is -3.5 mm. Humeral insert offset varies from -3.5 mm to 14.2 mm.

Overall Medialization of the Greater Tuberosity LO (Refer Table 6)
M-RSAs lead to a mean overall medialization of the greater tuberosity of 12.2 mm (range; 11.5-16.9 mm). ML-RSAs lead to a mean overall medialization of the greater tuberosity of 10.2 mm (range; 7.4-11.5 mm). L-RSAs lead to a mean overall medialization of the greater tuberosity of 4.9 mm (range; 2.8-6.6 mm). HL-RSAs lead to a mean overall medialization of the greater tuberosity of -0.25 mm (range; -1.7-1.8 mm). VHL-RSAs lead to a mean overall lateralization of the greater tuberosity of 4.5 mm.

DISCUSSION

The position of the joint center of rotation and humerus varies substantially amongst different RSA designs. The results of our study demonstrate a wide range in lateral offset, from the initial medialized concept designed by Grammont (13.1 mm) to more lateralized designs (up to 35.8 mm). The distribution between glenoid and humeral lateralization also varies substantially between different designs and their numerous possible configurations (Figure 3).

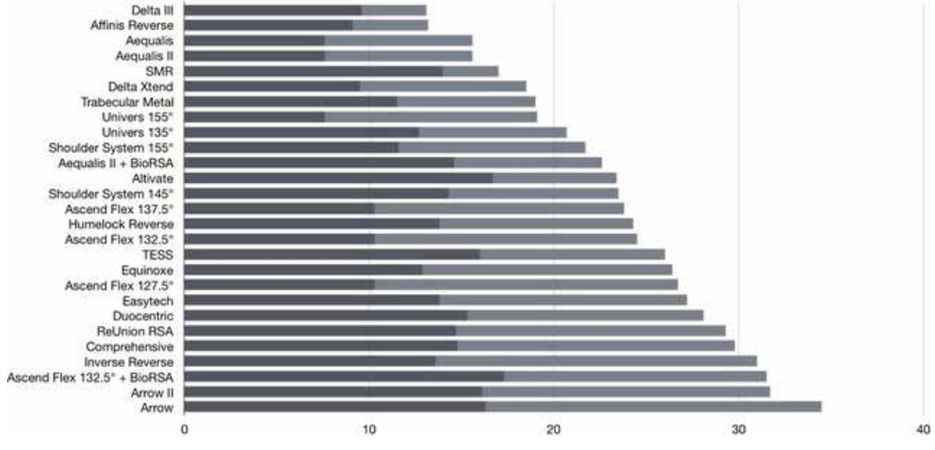

Figure 3
Distribution of glenoid and humeral lateral offset.
M: medialized RSA - ML: minimally lateralized RSA - L: lateralized RSA - HL: highly lateralized RSA - VHL: very highly lateralized RSA

The biomechanical effects of global lateralization have been investigated in numerous in vitro studies. However, although global lateralization may have common biomechanical theoretical effects, whether this lateralization takes place on the glenoid or humeral side may have different implications.

Some implants lateralize almost exclusively on the glenoid side. Glenoid lateralization can be achieved by modifying the shape of the glenosphere39, 40, lateralizing the baseplate11, 13 or increasing the length of the scapular neck with a bone graft10, 41. Lateralization on the glenoid side decreases scapular notching (the humeral polyethylene bearing is more distant from the scapular pillar10, 11, 13) and increases impingement-free motion7. However, since the center of rotation of the joint

Medialized implants follow Grammont's principles, leading to both humeral and glenoid medialization. These implants represent now a minority. Medialized designs may lead to poor restoration of internal and external rotation8, 27 (possibly due to a slackening of the remaining cuff or peripheral impingement), scapular notching33 (potentially leading to osteolysis, loosening, polyethylene wear, and tuberosity resorption3, 5, 8, 27, 29, 32, 34-38), instability8 (subsequent to slackening of the remaining cuff and maybe to the loss of the physiological wrapping angle of the deltoid from 48° to 8°15) and loss of contour of the shoulder8, 27, 34, 35

ends closer to the deltoid line of pull, the moment arm of the deltoid in elevation and abduction decreases16 and therefore the force required for the deltoid to perform abduction increases21; it may also increase acromial stress42. In addition, the glenoid implant is subjected to substantial shear forces, which could facilitate glenoid loosening39. Finally, the amount of glenoid lateralization is limited by glenoid bone erosion, inclination or retroversion39. None of the implants investigated in this study lateralizes more than 8.3 mm on the glenoid, a value that may be useful to keep in mind.

Humeral side lateralization can be achieved by various means. First, the stem may be modified from straight to curved43. Second, the humeral bearing may be embedded in the metaphysis (inlay) or rest on the humeral osteotomy (onlay)16. Shifting from an inlay to an onlay system lateralizes the humerus by displacing the stem away from the glenosphere. Implants evaluated in this study that lateralize on the humeral side have an onlay design (Table 4). Benefits of onlay systems include preservation of metaphyseal bone, ease of conversion44 and

additional modularity of the LO by medializing or lateralizing the connection between the humeral insert and stem (BC distance). Modification of the NSA from 155° to 145° or 135° has been described as a cause and/or a means of humeral lateralization. This study shows that the modification of the neck-shaft angle only leads to minimal lateralization: +3.2 mm between the humeral stem of the Delta III and the stem of the Altivate, which have a similar inlay design with a straight stem but different NSAs. The lateralization created by modifying the NSA is so minimal that it can be compensated by modifying the shape of the insert and the position of the connection between the insert and the stem (Arthrex). Therefore, it seems reasonable to consider that the angle of the humeral cut and the angle of the humeral insert have little influence on humeral and on global LO. However, humeral inserts with 135° angle decrease the risk of scapular notching without increasing instability45.

Humeral lateralization (whether in the stem or in the humeral insert) has several advantages. It restores a more anatomical position of the humerus and therefore of the lesser and greater tuberosities, which improves the length/tension curve of the remaining cuff. Better resting tension of the remaining cuff increases compressive forces on the joint and improves stability46. A more lateral position of the greater tuberosity increases the abductor lever arm and the wrapping angle of the deltoid,15 which could increase compressive forces6, 21, 47.

Three stemless implant have been included in our analysis. In these implants, stem lateralization can be introduced by the surgeon's choice of the location of the humeral cut. Indeed, line B can vary greatly depending on the height of the cut and the mediolateral position of the implant (Figure 4).

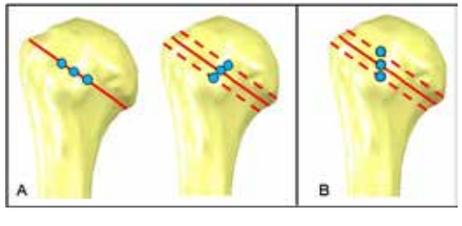

Figure 4
In stemless implants, stem lateralization does not exist but can be replaced by the surgeon's choice of humeral cut. Indeed, line B can vary greatly by modifying the height of the humeral cut and the medio-lateral position of the stemless implant (A). This is not true with a stemmed implant as in this setting, height of the humeral cut does not modify lateral offset (B)

Lateralization in both the humerus and the glenoid (LGLH, LGLH+) combines the beneficial effects of both glenoid and humeral lateralization but the risk is to lateralize excessively. Indeed, VHL implants lead to a mean greater tuberosity lateralization of 5.2 mm, which can be particularly problematic in smaller patients23 or in the presence of soft tissue contractures; resultant joint overstuffing may lead to poor motion, polyethylene wear21, 46, difficulty to reduce the joint, nerve stretching, difficulty to repair the subscapularis50 and acromial impingement. Therefore, if the objective is to restore an anatomical insertion of the remaining rotator cuff tendons and anatomical wrapping angle of the deltoid, mean greater tuberosity lateralization should be around 0 mm, which corresponds to HL implants. In addition, as the diameter of humeral heads has a 17 mm span, a similar 17 mm range should be available in order to restore anatomy in all patients.

Modification of the size of the glenosphere from a 36 mm diameter to a greater diameter has been considered a means of lateralization. However, our study shows that the modification from a 36 mm glenosphere to a 42 mm glenosphere leads only to a +1 mm increase in global lateral offset. Berhouet et al.20 found that a 7 mm glenoid lateralization on a 36 mm glenosphere led to a significant increase in impingement-free external and internal rotation in an experimental model. The increase was even greater when the glenosphere was changed from a 36 mm to a 42 mm diameter. This shows that the improvement in axial (internal and external) rotation found in their study is probably due to a 3-dimensional effect. Indeed, the main limitation of our study is to analyze 3-dimensional dynamic question using only static 2-dimensional measurements.

CONCLUSION

In conclusion, although it seems that some degree of lateralization is beneficial when performing a RSA, the ideal amount of global lateralization and the ideal contribution from the glenoid or from the humerus remain unknown. It probably varies depending on patient anatomy, quality and quantity of any remaining cuff, deltoid quality, and the amount of distalization of the humerus (arm and deltoid lengthening). This descriptive analysis can potentially help surgeons with implant selection as well to adapt the surgical technique depending on the expected lateral offset of the design being implanted (larger humeral cut, glenoid tilt, more glenoid reaming).

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Manufacturer	Implant	Humeral LO	Stem LO	Insert LO	Glenoid LO	Sphere LO	Baseplate LO	Global LO	Maximal LO	Range of LO
Arthrex	Univers 135°	8	13	-5	12.7	12.7	0	20.7	30.8	10.1
Arthrex	Univers 155°	11.5	14.5	-3	7.6	7.6	0	19.1	28.9	9.8
Aston	Duocentric	12.8	5.2	7.7	15.3	10.3	5	28.2	35.9	7.7
Biomet	Comprehensive	15	7.8	7.2	14.8	9.8	5	29.8	50.7	20.9
Biomet	TESS	10	11	-1	16	9	7	26	29.3	3.3
DJO	Altivate	6.7	8.5	-1.8	16.7	12.7	4	23.5	43.5	20.2[3]
DePuy	Delta III	3.5	7	-3.5	9.6	7.6	2	13.1	19.7	6.6
DePuy	DeltaXtend	9	8	1	9.5	8[1]	1.5	18.5	25.9	7.4
Exactech	Equinoxe	13.5	8.7	4.8	12.9	10.9[1]	2	26.4	37.1	10.7
FH Ortho	Arrow	18.2	5.5	12.7	16.3	7.6	8.7	34.5	39.3	4.8
FH Ortho	Arrow II	15.6	5.5	10.1	16.1	7.6	8.5	31.7	36.5	4.8
Fx Solutions	Humelock Reverse	10.5	8.5	2	13.8	10.3	3.5	24.3	33.5	9.2
Fx Solution	Easytech	13.4	8.5	4.9	13.8	10.3	3.5	27.2	33.7	6.5
Lima	SMR	3	6.5	-3.5	14	9	5	17	26.5	9.5
Lima	SMR Stemless	-	-	-2.2	17.9	12.9	5	-	-	-
Mathys	Affinis Reverse	4.1	9.5	-5.4	9.1	7.6	1.5	13.2	20.4	7.2
Medacta	Shoulder System 145°	9.2	7.5	1.7	14.3	10.3	4	23.5	34.5	11
Medacta	Shoulder System 155°	10.1	7.5	2.6	11.6	7.6	4	21.7	32.7	11
Strkyer	ReUnion RSA	14.6	7.5	7.1	14.7	12.7	2	29.3	44.7	16.8[2]
Tornier	Aequalis	8	7	1	7.6	7.6	0	15.6	21.9	6.3
Tornier	Aequalis II	8	7	1	7.6	7.6	0	15.6	22.9	7.3
Tornier	Aequalis II + BioRSA	8	7	1	14.6	7.6	7[3]	22.6	29.9	7.3
Tornier	Ascend Flex 127.5°	16.4	9.6	6.8	10.3	10.3	0	26.7	43.7	16.7
Tornier	Ascend Flex 132.5°	14.2	9.6	4.6	10.3	10.3	0	24.5	41.5	17
Tornier	Ascend Flex 137.5°	13.5	9.7	3.8	10.3	10.3	0	23.8	40.8	16.7
Tornier	Ascend Flex 132.5° + BioRSA	14.2	9.6	4.6	17.3	10.3	7[3]	31.5	48.5	17
Zimmer	Inverse Reverse	17.4	11	6.4	13.6	7.6	6	31	39	8
Zimmer	Trabecular Metal	7.5	7	0.5	11.5	9	2.5	19	35.5	16.5

Table 1
Lateral offset (LO) of the different implants included in the study.
1: smallest glenosphere available: 38 mm.
2: smallest glenosphere available: 32 mm.
3: lateralization is not in the baseplate but on the scapular neck
Humeral stem lateral offset for stemless implants has been calculated differently for the 3 stemless implants:
- Biomet TESS is available with a stem which has been used to calculate the stem lateral offset of the stemless version.
- FX Easytech has been overlapped to the position of the stem of the Fx Humelock to calculate the stem lateral offset.
- SMR stemless: humeral stem lateral offset could not be calculated as the design of the stemmed SMR implant is too different to overlap the two templates

Manufacturer	Implant	Global LO	Global Lateralization	Mean GT LO	Mean GT Medialization	Global Lateralization Class	Gleno-Humeral Construct	Glenoid contribution	Humeral Contribution
DePuy	Delta III	13.1	0	29.3	- 16.9	M	MGMH		
Mathys	Affinis Reverse	13.2	+ 0.1	29.4	-16.8		MGMH		
Tornier	Aequalis	15.6	+ 2.5	31.8	-14.4		MGMH		
Tornier	Aequalis II	15.6	+ 2.5	31.8	-14.4		MGMH		
Lima	SMR	17	+ 3.9	33.2	-13		MGMH		
DePuy	DeltaXtend	18.5	+ 5.4	34.7	-11.5	ML	MGLH	0 %	100%
Zimmer	Trabecular Metal	19	+ 5.9	35.2	- 11		MGMH	32%	68%
Arthrex	Univers 155°	19.1	+ 6	35.3	-10.9		MGLH	- 33%	133%
Arthrex	Univers 135°	20.7	+ 7.6	36.9	-9.3		MGMH	41%	59%
Medacta	Shoulder System 155°	21.7	+ 8.6	37.9	- 8.3		MGLH	53%	47%
Tornier	Aequalis II + BioRSA	22.6	+ 9.5	38.8	-7.4		LGMH	57%	43%
DJO	Altivate	23.4	+ 10.3	39.6	-6.6	L	LGMH	69%	31%
Medacta	Shoulder System 145°	23.5	+10.4	39.7	-6.5		MGLH	61%	39%
Tornier	Ascend Flex 137.5°	23.8	+ 10.7	40	-6.2		MGLH+	7%	93%
Fx Solutions	Humelock Reverse	24.3	+ 11.2	40.5	-5.7		MGLH	37%	63%
Tornier	Ascend Flex 132.5°	24.5	+ 11.4	40.7	-5.5		MGLH+	6%	94%
Biomet	TESS	26	+ 12.9	42.2	-4		LGLH	50%	50%
Exactech	Equinoxe	26.4	+13.3	42.6	-3.6		MGLH+	25%	75%
Tornier	Ascend Flex 127.5°	26.7	+ 13.6	42.9	-3.3		MGLH+	5%	95%
Fx	Easytech	27.2	+ 14.1	43.4	-2.8		MGLH	51%	49%
Aston	Duocentric	28.2	+ 15.1	44.4	-1.8	HL	LGLH	26%	74%
Strkyer	ReUnion RSA	29.3	+ 16.2	45.5	-0.7		LGLH+	31%	69%
Biomet	Comprehensive	29.8	+ 16.7	46	-0.2		LGLH+	31%	69%
Zimmer	Inverse Reverse	31	+ 17.9	47.2	1		MGLH+	22%	78%
Tornier	Ascend Flex 132.5° + BioRSA	31.5	+ 18.4	47.7	1.5		LGLH+	42%	58%
FH Ortho	Arrow II	31.7	+18.6	47.9	1.7		LGLH+	51%	41%
FH Ortho	Arrow	34.5	+ 21.4	50.7	4.5	VHL	LGLH+	31%	69%

Table 2
Global lateral offset (LO), global lateralization and greater tuberosity (GT) LO and medialization of the different implants included in the study.
M: medialized RSA - ML: minimally lateralized RSA - L: lateralized RSA - HL: highly lateralized RSA - HL: very highly lateralized RSA - MG: medialized glenoid - LG: lateralized glenoid - MH: medialized humerus - LH: minimally lateralized humerus - LH: lateralized humerus

Manufacturer	Implant	Glenoid LO	Glenoid Lat	Sphere LO	Sphere Lat	Baseplate LO	Baseplate Lat	Glenoid Lateralization Class
Arthrex	Univers 155°	7.6	- 2	7.6	0	0	- 2	MG
Tornier	Aequalis	7.6	- 2	7.6	0	0	- 2	
Tornier	Aequalis II	7.6	- 2	7.6	0	0	- 2	
Mathys	Affinis Reverse	9.1	- 0.5	7.6	0	1.5	- 0.5	
DePuy	DeltaXtend	9.5	- 0.1	8[1]	+ 0.4	1.5	- 0.5	
DePuy	***Delta III***	***9.6***	***0***	***7.6***	***0***	***2***	***0***	
Tornier	Ascend Flex 127.5°	10.3	+ 0.7	10.3	+ 2.7	0	- 2	
Tornier	Ascend Flex 132.5°	10.3	+ 0.7	10.3	+ 2.7	0	- 2	
Tornier	Ascend Flex 137.5°	10.3	+ 0.7	10.3	+ 2.7	0	- 2	
Zimmer	Trabecular Metal	11.5	+ 1.9	9	+ 1.4	2.5	+ 0.5	
Medacta	Shoulder System 155°	11.6	+2	7.6	0	4	+2	
Arthrex	Univers 135°	12.7	+ 3.1	12.7	**+ 5.1**	0	- 2	
Exactech	Equinoxe	12.9	+ 3.3	10.9[1]	+ 3.3	2	0	
Zimmer	Inverse Reverse	13.6	+ 4	7.6	0	6	+ 4	
Fx Solutions	Humelock Reverse	13.8	+ 4.2	10.3	+ 2.7	3.5	+ 1.5	
Fx Solutions	Easytech	13.8	+ 4.2	10.3	+ 2.7	3.5	+ 1.5	
Lima	SMR	14	+ 4.4	9	+ 1.4	5	+ 3	
Medacta	Shoulder System 145°	14.3	+ 4.7	10.3	+ 2.7	4	+ 2	
Tornier	Aequalis II + BioRSA	14.6	**+ 5**	7.6	0	7[1]	**+ 5**	LG
Strkyer	ReUnion RSA	14.7	**+ 5.1**	12.7	**+ 5.1**	2	0	
Biomet	Comprehensive	14.8	**+ 5.2**	9.8	+ 2.2	5	+ 3	
Aston	Duocentric	15.3	**+ 5.7**	10.3	+ 2.7	5	+ 3	
Biomet	TESS	16	**+ 6.4**	9	+ 1.4	7	**+ 5**	
FH Ortho	Arrow II	16.1	**+ 6.5**	7.6	0	8.5	**+ 6.5**	
FH Ortho	Arrow	16.3	**+ 6.7**	7.6	0	8.7	**+ 6.7**	
DJO	Altivate	16.7	**+ 7.1**	12.7	**+ 5.1**	4	+ 2	
Tornier	Ascend Flex 132.5° + BioRSA	17.3	**+ 7.7**	10.3	+ 2.7	7[1]	**+ 5**	
Lima	SMR Stemless	17.9	**+ 8.3**	12.9	**+ 5.3**	5	+ 3	

Table 3
Glenoid lateral offset (LO) and lateralization of the different implants included in the study.
1: smallest glenosphere available: 38 mm. - 2: lateralization is not in the baseplate but on the scapular nec

		Glenoid Lateral Offset			Global Lateral Offset		
Manufacturer	**Implant**	***36 mm.***	***Larger glenosphere[1] : 39/40/41/42 /44 mm.***	***Lateralization***	***36 mm.***	***Larger glenosphere[1] : 39/40/41/42/44 mm.***	***Lateralization***
Arthrex	Univers 135 (39 mm.)	12.7	13.8	1.1	20.7	21.8	1.1
Arthrex	Univers 155 (39 mm.)	7.6	8.2	0.4	19.1	19.7	0.7
Aston	Duocentric (40 mm.)	15.3	17	1.7	28.2	29.9	0.7
Biomet	Comprehensive (41 mm.)	14.8	16.2	1.4	29.8	31.6	1.8
Biomet	TESS (41 mm.)	16	17.3	1.3	26	28.3	2.3
DJO	Altivate (40 mm.)	16.7	15.6	-1.1	23.5	23.1	-0.4
DePuy	Delta III (42 mm.)	9.6	9.9	0.3	13.1	13.4	0.3
DePuy	DeltaXtend (42 mm.)	9.5[1]	10.4	0.9	18.5[1]	19.9	1.4
Exactech	Equinoxe (42 mm.)	12.9[1]	14	1.1	26.4[1]	38.1	2.3
FH Industrie	Arrow (39 mm.)	16.3	17.8	1.5	34.5	36.4	1.9
FH Industrie	Arrow II (39 mm.)	16.1	17.7	1.6	31.7	33.8	2.1
Fx Solutions	Humelock Reverse (40 mm.)	13.8	15	1.2	24.3	25	0.7
Fx Solutions	Easytech (40 mm.)	13.8	15	1.2	27.3	28.4	1.1
Lima	SMR (44 mm.)	14	16	2	17	19	2
Lima	SMR Stemless (44 mm.)	17.9[1]	19.1	1.2	-	-	-
Mathys	Affinis Reverse (39 mm.)	9.1	9.7	0.6	13.2	13.3	0.1
Medacta	Shoulder System 145° (39 mm.)	14.3	15.2	0.9	23.5	24.2	0.7
Medacta	Shoulder System 155° (39 mm.)	11.6	12.2	0.6	21.7	22.5	0.8
Strkyer	ReUnion RSA (40 mm.)	14.7	16.1	1.4	29.3	30.7	1.4
Tornier	Aequalis (42 mm.)	7.6	9.9	2.3	15.6	19.9	4.3
Tornier	Aequalis II (42 mm.)	7.6	8.9	1.3	15.6	18.9	3.3
Tornier	Ascend Flex 132.5 (42 mm.)	10.3	12	1.7	27	29	2
Zimmer	Inverse Reverse (40 mm.)	13.6	14.5	0.9	31	32	1
Zimmer	Trabecular Metal (36 mm.)	11.5	12.5	1	19	20.5	1.5

Table 4
Influence of glenosphere size on lateral offset
1 : 38 mm. - 2 : 40 mm.

Manufacturer	Implant	Inlay / Onlay	Insert NSA	Humeral LO	Stem LO	Stem Lat	Insert LO	Insert Lat	Humeral Lateralization Class
Lima	SMR stemless	Inlay	140	-	-	-	-2.2	+ 1.3	MH
Lima	SMR	Inlay	150	3	6.5	- 0.5	-3.5	0	
DePuy	***Delta III***	***Inlay***	***155***	***3.5***	***7***	***0***	***-3.5***	***0***	
Mathys	Affinis Reverse	Inlay	155	4.1	9.5	+ 2.5	-5.4	- 1.9	
DJO	Altivate	Inlay	135	6.7	8.5	+ 1.5	-1.8	+ 1.7	
Zimmer	Trabecular Metal	Inlay	150	7.5	7	0	0.5	+ 4	
Arthrex	Univers 135°	Semi-Inlay	135	8	13	**+ 6**	-5	- 1.5	
Tornier	Aequalis	Inlay	155	8	7	0	1	+ 4.5	
Tornier	Aequalis II	Inlay	155	8	7	0	1	+ 4.5	
Tornier	Aequalis II + BioRSA	Inlay	155	8	7	0	1	+ 4.5	
DePuy	DeltaXtend	Inlay	155	9	8	+ 1	1	+ 4.5	LH
Medacta	Shoulder System 145°	Semi-Inlay	145	9.2	7.5	+ 0.5	1.7	**+ 5.2**	
Biomet	TESS	Inlay	150	10	11	+ 4	-1	+ 2.5	
Medacta	Shoulder System 155°	Semi-Inlay	155	10.1	7.5	+ 0.5	2.6	**+ 6.1**	
Fx Solutions	Humelock Reverse	Inlay	145	10.5	8.5	+ 1.5	2	**+ 5.5**	
Arthrex	Univers 155°	Semi-Inlay	155	11.5	14.5	+ 7.5	-3	+ 0.5	
Aston	Duocentric	Onlay	145	12.8	5.2	- 1.8	7.7	**+ 11.2**	
Fx Solutions	Easytech	Onlay	145	13.4	8.5	+ 1.5	4.9	**+ 8.4**	
Tornier	Ascend Flex 137.5°	Onlay	145	13.5	9.7	+ 2.7	3.8	**+ 7.3**	LH+
Exactech	Equinoxe	Onlay	145	13.5	8.7	+ 1.7	4.8	**+ 8.3**	
Tornier	Ascend Flex 132.5°	Onlay	145	14.2	9.6	+ 2.6	4.6	**+ 8.1**	
Tornier	Ascend Flex 132.5° + BioRSA	Onlay	145	14.2	9.6	+ 2.6	4.6	**+ 8.1**	
Strkyer	ReUnion RSA	Onlay	135	14.6	7.5	+ 0.5	7.1	**+ 10.6**	
Biomet	Comprehensive	Onlay	147	15	7.8	+ 0.8	7.2	**+ 10.7**	
FH Ortho	Arrow II	Onlay	155	15.2	5.5	- 1.5	10.1	**+ 13.6**	
Tornier	Ascend Flex 127.5°	Onlay	145	16.4	9.6	+ 2.6	6.8	**+ 10.3**	
Zimmer	Inverse Reverse	Onlay	155	17.4	11	+ 4	6.4	**+ 9.9**	
FH Ortho	Arrow	Onlay	155	18.2	5.5	-1.5	12.7	**+ 16.2**	

Table 5
Humeral lateral offset (LO) and lateralization of the different implants included in the study.
In bold and italic characters: values of the Delta III implant considered to be the baseline for all measurements.
In bold characters: values of lateralization greater than +5 mm.

32/ THE BIOMECHANICS OF REVERSE SHOULDER ARTHROPLASTY POLYETHYLENE INSERT CONSTRAINT

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INTRODUCTION

Reverse total shoulder arthroplasty (RSA) is a common and successful treatment option for cuff tear arthropathy, arthritis, complex fractures and as a revision procedure for failed primary arthroplasty[1-10]. Implant instability is a complication that can be encountered intra-operatively and/or post-operatively following RSA. A surgical management option for instability is use of a polyethylene insert with increased constraint (or increased cup depth) to achieve implant stability. Alternatively, some implant manufacturers in an attempt to increase range of motion, offer higher mobility polyethylene inserts, which have decreased cup depth. These lower-constraint inserts are theorized to allow greater range of motion before insert related impingement that blocks further motion. At present, there is a paucity of information regarding the effects of constraint on joint load and resultant joint load angle[13]. Also, it is believed that increasing polyethylene constraint increases stresses on the glenoid base plate with increased shear and altered joint loading.
The purpose of this biomechanical study was to investigate the effects of altering humeral polyethylene insert constraint on joint load, joint load angle, deltoid force, and ROM in RSA. We hypothesized that loading parameters would not be significantly different due to the unaltered centre of rotation, but that ROM would decrease with increased constraint.

MATERIALS AND METHODS

Experimental RSA Implant

A custom modular RSA implant system was used that allowed for the polyethylene insert constraint to be changed and the articular joint load to be measured using an integrated six degrees-of-freedom (DOF) load sensor, which was inserted between the native glenoid baseplate and the glenosphere (Figure 1).

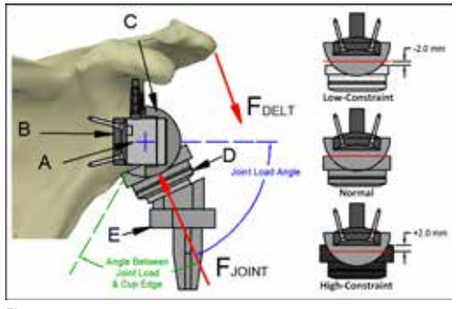

Figure 1
Custom modular instrumented reverse total shoulder arthroplasty implant (left) with load sensing device (A), glenoid base plate (B), glenosphere (C), adjustable humeral insert constraint level (D), and humeral component (E); and the three humeral cup constraints investigated (right) including low-constraint, normal, and high-constraint. The implant center of rotation is constant for all constraints tested, and shown as a blue cross at the center of the glenosphere.

One of three commercially available polyethylene inserts (Delta XTEND, Dupuy, Warsaw, IN) of varying cup depths including low-constraint (shallow cup), standard (normal), and high-constraint (deep cup) were attached to the humeral component, which was configured to have a 155 head-neck angle and 0 retroversion. The glenoid base plate was secured to the inferior aspect of the glenoid with the center of rotation at the glenoid articulation7.

Specimen Preparation and Study Protocol

The study RSA was implanted into in 6 cadaveric shoulders using a deltopectoral approach. Access to the glenohumeral joint was achieved by elevating the subscapularis muscle off the scapula with preservation of its tendinous attachment to the proximal humerus. Complete tears of the supraspinatus and the superior infraspinatus tendons were then simulated via resection. The 6 degree-of-freedom load cell was inserted into the glenoid vault, such that the glenoid base plate was positioned flush and on the inferior rim of the glenoid. Humeral lengthening was standardized by consistently aligning the lateral edge of the cup with the greater tuberosity of the humerus. The three deltoid heads were secured at their insertion mid-humerus, and the musculotendious junctions of the remaining rotator cuff were secured with a running locking stitch. The scapula was then attached to a shoulder simulator capable of independently loading the muscles around the shoulder girdle to produce active glenohumeral and scapulothoracic motion, and optical trackers were affixed to both the scapula and to an intramedullary rod inserted into the humerus. All muscles were coupled to pneumatic actuators using physiologic lines-of-action (Figure 2) and loading was dictating using a previously validated kinematics driven muscle loading control system[14, 15].

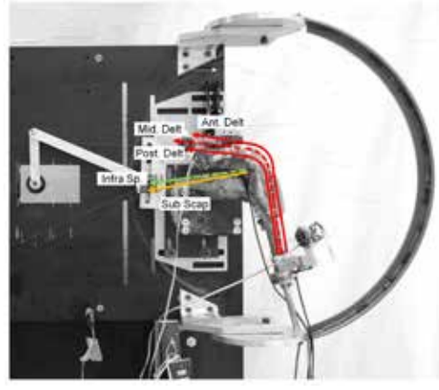

Figure 2
Lines of action of the three heads of the deltoid (red), infraspinatus (green), and subscapularis (orange) muscles.

For each shoulder, the testing order of the constraint conditions was randomized. Three humeral polyethylene insert conditions were tested (low-constraint, standard, high-constraint). For each condition, active abduction was simulated from 0° to 90° at 1°/sec with scapular rotation applied at a 2:1 glenohumeral-to-scapulothoracic ratio[16]. Internal rotation (IR) and external rotation (ER) range of motion (ROM) were assessed at 0° of flexion/extension and abduction both actively and passively. Maximum active IR was recorded when the subscapularis, infraspinatus and anterior deltoid muscles were ramped to 38N, 6N and 6N, respectively. Maximum ER ROM was recorded when the infraspinatus, subscapularis, and posterior deltoids and middle deltoids were ramped to 27N, 9N, 8N, and 6N, respectively. These muscle loads were derived from loading ratios in the literature for these two motions[17, 18]. Passive testing was performed with 0.8Nm of torque applied to the humerus, while the deltoids and rotator cuff tendons were loaded to 5N and 7.5N, respectively[19, 20]. Passive abduction and adduction ROM of the humerus was recorded when the humerus encountered bony, implant or soft tissue resistance.

Outcomes and Statistics

The effects of poly constraint on joint load, joint load angle and total deltoid force during active abduction was measured at 7.5° increments between 22.5° and 82.5° of abduction, which was the range over which all specimens achieved active abduction. The effect of polyethylene constraint on range of motion was assessed using peak internal rotation and external rotation angles, and peak adduction and abduction angles for both active and passive testing.
A two-way repeated measure ANOVA was carried out for joint load, joint load angle, and deltoid force with a significance level of ($p<0.05$), and a paired t-test for the range of motion outcomes. Sample size calculations were performed for each outcome variable and it was shown that ≥80% power could be achieved in each with the use of six specimens.

RESULTS

No significant effects on RSA joint load were detected throughout active abduction when polyethylene insert constraint was altered ($p=0.42$). Joint load was lowest at the beginning of active abduction and reached maximum levels during mid-abduction. The maximum loads achieved were 62±9, 64±9, and 62±9 percent of Body Weight (%BW) for the low-, standard, and high-constraint polyethylene inserts, respectively, at an abduction angle of approximately 60 degrees (Figure 3).

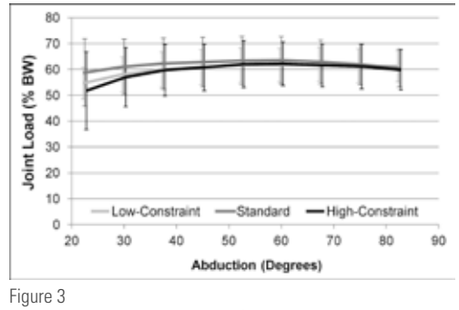

Figure 3
Mean (±1 standard deviation) RSA joint load versus abduction angle for all three polyethylene insert constraints investigated (low, standard, high-constraint).

Joint load angle decreased as abduction angle increased, ranging from 32±6°, 36±8°, and 34±6° at the beginning of abduction to 12±6°, 14±6°, and 14±4° at the end of abduction for the low-, standard, and high-constraint polyethylene inserts, respectively. No significant effects were detected for polyethylene constraint on joint load angle ($p=0.186$).
When polyethylene insert constraint was altered, we did not find a significant effect on total deltoid force required to achieve active abduction ($p=0.144$, Figure 4), which reached maximum values of 66±7, 69±9 and 67±9 %BW for the low-, standard, and high-constraint polyethylene inserts, respectively.

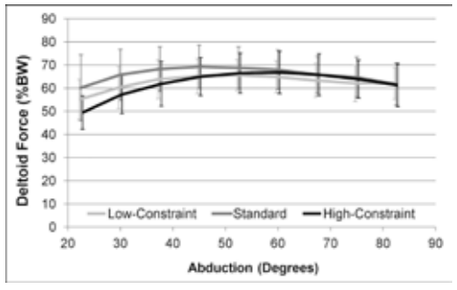

Figure 4
Mean (±1 standard deviation) deltoid force required to achieve active shoulder abduction versus abduction angle for all three polyethylene insert constraints investigated (low, standard, and high-constraint)

No significant differences in abduction ROM were detected between the low, standard, and high-constraint polyethylene inserts (p>0.5 for all). The peak adduction angles obtained for the low, standard and high-constraint polyethylene inserts were -1±7°, 0±4°, and -1±8° respectively; and the peak abduction angles obtained were 81±8°, 79±10°, and 79±9°, respectively (Figure 5).

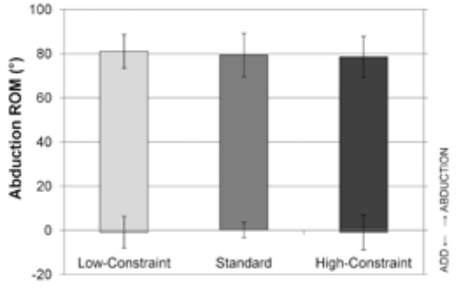

Figure 5
Mean (±1 standard deviation) abduction arc of motion for all three polyethylene insert constraints investigated (low, standard, and high-constraint)

With respect to both passive and active internal and external rotation, no statistically significant differences were found when the standard polyethylene insert was replaced with the low-constraint insert (p>0.242 for passive, p>0.241 for active) or with the high-constraint insert (p>0.368 for passive, p>0.150 for active). However, when comparing the low-constraint insert (mean external rotation 57±26°) to the high-constraint insert (mean external rotation 51±27°), there was a statistically significant increase in passive external rotation (p=0.038, Figure 6).
Altering polyethylene constraint was found to significantly affect the angle between the joint load and the edge of the polyethylene cup (p<0.001). The standard insert had a mean joint load to polyethylene cup edge angle of 50±5° throughout abduction, whereas the low-constraint polyethylene insert had a lower mean angle of 40±5° (p<0.001), and the high-constraint polyethylene insert had an higher angle of 62±4° (p<0.001).

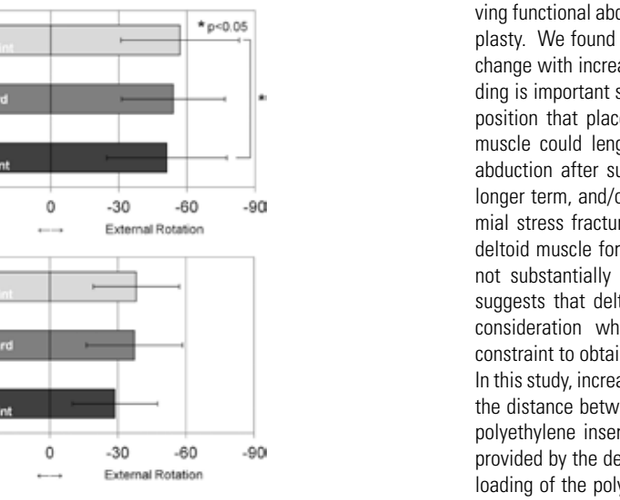

Figure 6
Mean (±1 standard deviation) passive (top) and active (bottom) range of motion in internal (left) and external (right) range of motion for all three polyethylene insert constraints investigated (low, standard, high-constraint)

DISCUSSION

Obtaining and maintaining a stable articulation is a vital component to the success of total joint arthroplasty. Similar to total hip arthroplasty[21,22], increasing cup constraint in reverse total shoulder arthroplasty has been shown to enhance overall stability of the prosthesis[23]. However, very little has been done to investigate the effects of increasing polyethylene constraint on joint load, load angle, deltoid force and range of motion in reverse total shoulder arthroplasty.
Knowledge of the joint load and the load angle, especially as it pertains to a reverse total shoulder arthroplasty implant, is important as it characterizes the magnitudes and types of forces experienced by the modular connections, the bearing surface and the implant, including the glenoid baseplate. Increased forces, and in particular shear, can affect glenoid baseplate fixation and may result in incomplete bone ongrowth or possibly implant failure. Our findings suggest that increasing polyethylene constraint to enhance joint stability will have limited effect on the resultant joint load. Therefore, the baseplate does not experience increased shear with increased constraint. This is counter intuitive to traditional beliefs that increasing RSA constraint will increase glenoid baseplate shear and potential failure. The results of this study support our hypothesis and are logical since the center of rotation is unchanged when increasing or decreasing polyethylene constraint in an already constrained articulation.
The deltoid is the most important muscle group in achieving functional abduction in reverse total shoulder arthroplasty. We found that deltoid force did not substantially change with increased polyethylene constraint. This finding is important since any implant configuration or joint position that places increased demands on the deltoid muscle could lengthen the time for recovery of active abduction after surgery, increase deltoid fatigue in the longer term, and/or potentially increase the risk of acromial stress fractures[24, 25]. Our finding that the required deltoid muscle force for achieving active abduction was not substantially increased with increasing constraint, suggests that deltoid fatigue may not be an important consideration when increasing humeral polyethylene constraint to obtain optimal stability.
In this study, increasing polyethylene constraint increased the distance between the joint load and the edge of the polyethylene insert by virtue of the larger contact area provided by the deeper insert, which results in less edge loading of the polyethylene. A retrieval study by Day et al26 found that inferior rim damage was the predominant feature of polyethylene damage in reverse total shoulder arthroplasty. Therefore, moving the joint load away from the edge of the cup by increasing constraint, as seen in our study, may have a positive impact on wear characteristics and long term RSA performance by reducing edge loading. However, this increased constraint may also have a negative impact by increasing scapular impingement that may occur due to the increased inferomedial overhang of the deeper polyethylene insert. Further studies are required to assess both of these factors to determine at what point an optimized design can be created that maximizes wear characteristics and minimizes notching.
Interestingly, in the present study we found that abduction range of motion was not significantly different with increasing polyethylene insert constraint. This was unexpected, particularly because Gutierrez et al have reported in a computer-simulated study that the combination of placing the glenoid component inferiorly as we did in our study and increasing polyethylene constraint significantly reduced abduction range of motion[13]. We suspect that the variance from the computer-simulation study of Guteirrez et al[13] likely occurred because we used cadaveric specimens, which more closely replicate the in situ scenario, that resulted in terminal motion restriction by soft tissue and/or bony impingement, rather than implant-related, or constraint-related restriction. Additionally, during implantation, we endeavoured to place our glenoid component in the optimum position, as inferior as possible on the glenoid to limit impingement. It is conceivable, that if the glenoid implant would have been placed more superior, that constraint related differences in polyethylene impingement would have been more apparent. Our results with rotational range of motion, however, were significantly affected by polyethylene insert constraint. As polyethylene constraint increase, there was a statistically significant reduction in active external rotation. Interestingly, there were no significant differences with passive external rotation or active/passive internal rotation. Additionally, the increased external rotation obtained with the low-constraint polyethylene insert occurred past 30 degrees of external rotation, which may not be clinically achievable in patients with rotator cuff tear arthropathy.
As with all biomechanical cadaveric studies, our research does have some limitations. Using cadavers makes it difficult to replicate precise physiological conditions such as soft tissue properties; however, this is somewhat mitigated in this investigation of reverse total shoulder arthroplasty, because many soft tissues are released as part of the study protocol to replicate clinical rotator cuff tear arthropathy. Furthermore, it should be noted that the muscle groups loaded in this study were not representative of all patients treated with reverse total shoulder arthroplasty as some patients have complete rotator cuff disruption whereas we chose to simulated cuff tear arthropathy with an intact posterior infraspinatus and teres minor.

CONCLUSIONS

Increasing polyethylene constraint in RSA to enhance implant stability does not significantly alter resultant joint loads, glenoid baseplate shear or deltoid forces. These findings are logical, as the centre of rotation is unchanged in an already highly constrained articulation. Increasing polyethylene constraint also does not significantly affect abduction range-of-motion, as terminal motion was limited by bone and/or soft tissue structures rather than polyethylene insert impingement in an ideally placed glenosphere. However, active external rotation was significantly decreased with increased polyethylene insert constraint. Finally, joint load migrated further from the edge of the polyethylene insert (was more centrally located in the polyethylene) when constraint was increased. Overall, in our biomechanical simulator model increasing polyethylene constraint, to enhance stability in a clinically unstable arthroplasty scenario, had minimal affects on RSA kinematics.

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33/ CORRELATION BETWEEN DISTALIZATION AND LATERALIZATION AND CLINICAL OUTCOMES IN REVERSE SHOULDER ARTHROPLASTY

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INTRODUCTION

Paul Grammont introduced the innovative project of the reverse shoulder arthroplasty (RSA) that consisted of a large glenoid hemisphere without neck and a small humeral cup with the almost horizontal inclination of 155o [1,2]. By this way the center of rotation is medialized and remains in contact with the bony surface of the glenoid, while some fibers of the anterior and posterior deltoid can act as active abductors [3]. Also, the humerus is significantly distalized relatively to acromion in order to restore deltoid muscle tension [3]. The "Grammont's prosthesis" successfully restored forward flexion, eliminated pain and improved significantly the overall function of the shoulder joint even after 10 years post-operatively [4–6].
However, this type of RSA configuration can have some "disadvantages". As a non anatomic prosthesis, it usually leads to limited external or internal rotation [3,7], arm lengthening with possible neurologic injuries in some cases [8,9] and scapular notching in rates up to 88% over the time [4]. Recently several authors proposed that a more lateralized and a less "distalized" position of the RSA could improve the functional outcomes [7,10–13]. At the glenoid side this could be performed either with a bone autograft (Bony Increased-Offset Reverse Shoulder Arthroplasty-BIO-RSA) [11], either with an increased offset of the glenosphere [12] or of the baseplate [13]. Furthermore, at the humeral side any lateralization could be achieved either by decreasing the humeral stem inclination or by using curved stems with onlay systems eccentric or not [7,10,14].
Three-dimensional computer assisted or cadaveric models showed that the lateralization and distalization can affect significantly the postoperative range of motion of the RSA [7,15,16]. Nevertheless, the effects of these parameters remain unclear in vivo. Furthermore, is very difficult to evaluate post-operatively the amount of lateralization and distalization achieved. Our hypothesis was that the lateralization of the RSA either at the glenoid or at the humeral side results to a less distal position of the prosthesis and could improve the final range of motion. Additionally, the final position of the RSA can be estimated with two different angles; the "Lateralization Shoulder Angle" (LSA) and the "Distalization Shoulder Angle" (DSA) that are directly correlated to the final clinical outcomes regardless of the type of the prosthesis used.

MATERIALS AND METHODS

We retrospectively reviewed all the patients that underwent RSA for the treatment of rotator cuff arthropathy between 2009 and 2015 in our department. In order to evaluate the different types of lateralization and distalization we included patients with two different humeral stems; the traditional Grammont-style stem with 155o inclination (Wright,Tornier Inc, Houston, TX, USA) and the newer short curved anatomical stem with 145o final construct inclination (Ascend Flex; Wright Tornier, TX, USA). Additionally, at the glenoid side we included patients with or without a Bony Increased-offset Reversed Shoulder Arthroplasty (BIO-RSA). According to the combination of the implants used, four (4) groups of patients were formed: Group I (Grammont Style stem-No BIO-RSA); Group II (Ascend Flex stem- No BIO-RSA); Group III (Grammont Style stem with BIO-RSA); and Group IV (Ascend Flex stem with BIO-RSA).
At the latest follow up (minimum two years) the following data were collected: the range of motion (ROM); the absolute Constant score; the subjective shoulder values (SSV); the Simple Shoulder Test (SST); the American Shoulder and Elbow Surgeons Shoulder Score (ASES); and the ADLER score for functional evaluation of the active external rotation.
Finally, on the latest true anteroposterior radiographs we measured the "Lateralization Shoulder Angle" (LSA) and the "Distalization Shoulder Angle" (DSA) [17]. As already published the LSA is formed by the following three bony landmarks; the superior glenoid tubercle, the most lateral border of the acromion and the most lateral border of the greater tuberosity [Figure 1].

Figure 1

Also the DSA is defined by the superior glenoid tubercle, the most lateral border of the acromion and the most superior border of the greater tuberosity [Figure 2].

Figure 2

Both angles have shown substantial to almost perfect intra- and inter-rater agreement [17].
The patients' characteristics were compared between the four groups of RSA using the Kruskal-Wallis H test test for continuous variables, and the Chi-square test for discrete variables. Linear regression or correlation analysis was conducted between the final functional outcomes and the 'amount' of RSA lateralization and distalization expressed by the LSA and DSA.

RESULTS

Finally 46 met the inclusion criteria; 13 patients in Group I (Grammont Style stem-No BIO-RSA); 10 patients in Group II (Ascend Flex stem- No BIO-RSA); 11 patients in Group III (Grammont Style stem with BIO-RSA); and 12 patients in Group IV (Ascend Flex stem with BIO-RSA). Thirty-seven patients were female and 9 male with mean age 77±7.5 years (range 62 -90). In 29 cases the right shoulder was operated and in the remaining 17 the left side. The mean follow up was 39±18 months (range 24-84).
The active forward flexion, the active abduction and the final functional scores were similar among the four groups of patients as shown in Table 1.
However, when the combination of the used implants resulted in a more lateralized position of the RSA, the active external rotation in position 1 was significantly higher (p=0.027, Table 1). Similarly, the values of the LSA were also higher in the same groups of patients (p=0.001, Table 1).

Table 1
Overall results according to Reverse Shoulder Arthroplasty Type

	Group I	Group II	Group III	Group IV	P values
Age	77±2 (62-86)	77±2 (62-89)	76±2 (67-90)	76.5±2.5 (64-90)	p=0.915
Active Forward Flexion	148±6.5° (100-170°)	149±8° (90-175°)	158±4° (130-175°)	152±8° (80-180°)	p=0.749
Active Abduction	134±8.5° (90-170°)	134±9° (80-175°)	145±7° (100-170°)	129±11 (60-170°)	p=0.805
Active External Rotation	14±4° (-10- 35°)	30.5±4° (15-60°)	24±4° (0-40°)	30±5° (0-50°)	**p=0.027**
Active Internal Rotation (Level)	L3 (BUT-T12)	LS (BUT-T12)	L3 (BUT-T12)	L3 (BUT- T7)	p=0.374
Pre-op Absolute Constant Score	23±3 (12-45)	21±2.5 (8-30)	19±3.5 (2-33)	26±1 (16-34)	p=0.238
Post-op Absolute Constant Score	62±3 (45-71)	67±4 (41-86)	65±2 (53-77)	62±5 (34-87)	p=0.895
Simple Shoulder Test (SST)	7±0.5 (4-11)	7±1 (2-12)	7±0.8 (3-11)	7±1 (1-11)	p=0.992
ASES score	75±4 (53-98)	79±5 (53-100)	77±4 (57-98)	72±8 (33-100)	p=0.938
Subjective shoulder values (SSV)	70±4 (50-90)	69±5.5 (40-95)	77±4 (50-90)	74±6 (40-95)	p=0.566
ADLER	26±1(15-30)	27±1 (22-30)	27±1 (23-30)	27±1(14-30)	p=0.779
Lateralization Shoulder Angle (LSA)	74±1° (67-85°)	83±2° (68-95°)	80±2° (68-91°)	89±3 (65-105°)	**p=0.001**
Distalization Shoulder Angle (DSA)	55±4° (35-75°)	52±3° (40-71°)	53±3° (40-66°)	49±4° (28-75°)	p=0.58

Correlation analysis of the lateralization with the final functional outcomes

A statistically significant positive linear regression (R2=0.42, p<0.001) was found between the final external rotation and the value of the LSA [Figure 3].

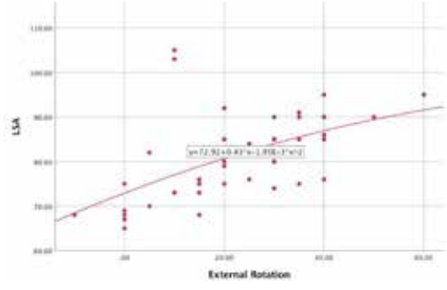

Figure 3

The same linear pattern was found between the active anterior elevation (AAE) and the LSA (R2=0.2, p=0.008). Therefore, the Spearman's correlation revealed a positive correlation between the value of the LSA and the ADLER score (rs=0.4, p=0.007), the Constant score (rs=0.29, p=0.05) and mainly with the mobility part of the absolute Constant score (rs=0.5, p=0.003).
However, no significant correlations were found between the LSA and the subjective scores of ASES (rs=0.025, p=0.868), SST (rs=0.029, p=0.849) and SSV (rs=0.2, p=0.18).

Correlation analysis of the distalization with the final functional outcomes

A significant negative linear regression was observed between the DSA and the final external rotation (R2=0.22, p=0.002) and active anterior elevation (R2=0.2, p=0.004) [Figure 4].

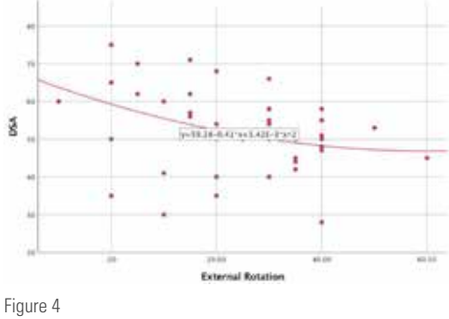

Figure 4

Similarly, the Spearman's correlation revealed a negative correlation between the value of the DSA and the ADLER score (rs=-0.3, p=0.04) and the mobility part of Constant score (rs=-0.324, p=0.028). No significant correlations were found between the DSA and the subjective scores of ASES (rs=-0.097, p=0.52), SST (rs=-0.081, p=0.6) and SSV (rs=-0.17, p=0.259).
In all cases that the DSA was >70o the patients presented with persistent pain, paresthesias, causalgias, limited ROM and over-tensioned deltoid and biceps muscles.
Finally, a strong negative correlation was found between the lateralization and distalization effect as expressed by the values of LSA and DSA (rs=-0.7, p<0.001).

DISCUSSION

The most important finding of our study was that the lateralization and distalization of the RSA (as evaluated by the LSA and DSA) were directly correlated with the functional outcomes and mainly with the final range of motion of the shoulder joint [Figures 5, 6].

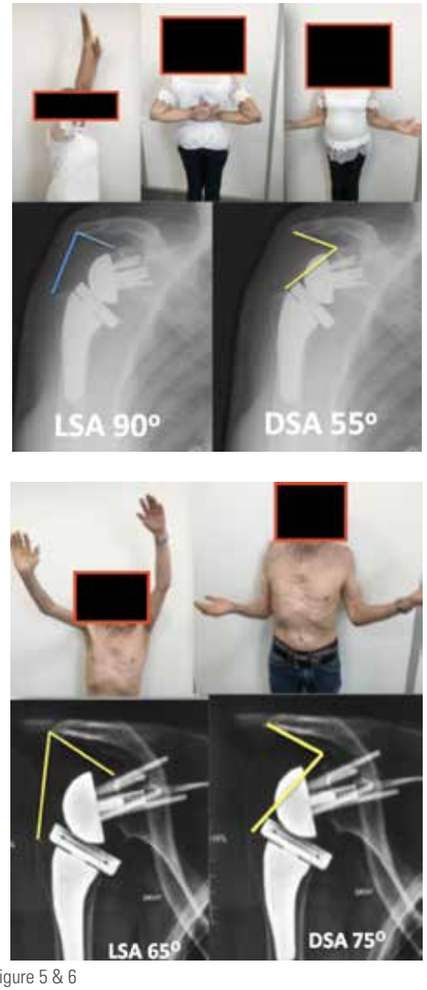

Figure 5 & 6

Despite that the LSA and DSA are not an exact measurement of the lateralization and distalization of the RSA final construct, we confirmed the negative correlation between them in the clinical setting. Therefore, the more medially the arthroplasty is positioned (lower LSA) the greater is the distance between the humerus and the acromion respectively (larger DSA). The latest corresponds to the original Grammont type prosthesis [3].

Furthermore, in our study population the newer short curved anatomical stem with inclination of 145o with or without the use of the BIO-RSA at the glenoid side resulted in a more lateralized position of the final RSA construct. We found a positive correlation between this amount of lateralization (expressed by the LSA) and the final external rotation, forward flexion, Constant score (mainly the mobility part) and the ADLER score. Similar results were also reported with newer computer based models [7,15,18] or in clinical studies that used the BIO-RSA or the metallic lateralization of the center of rotation [11,13,19].

One of the main principles of the RSA is to lower the humerus relatively to the acromion in order to restore or even increase the tension of the deltoid muscle and improve active forward flexion of the shoulder joint [3]. Several authors have attempted to perform an objective measurement of the acromiohumeral distance in post-operative x-rays. However, the predictive value of this distance, regarding the final ROM, was not always evident [20,21]. We found a negative linear regression of the DSA with the post-operative active forward flexion and in cases of DSA> 70o all patients showed limited AAE (<110o), persistent pain, causalgias and paresthesias.

CONCLUSIONS

The "lateralization and distalization" effect after RSA could be estimated with two different angles; the Lateralization Shoulder Angle" (LSA) and the "Distalization Shoulder Angle" (DSA). The final range of motion of the shoulder joint is directly correlated to the values of both angles and it could be predicted with good to excellent sensitivity and specificity.

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34/ THE RELATIONSHIP BETWEEN POST-OPERATIVE INTEGRITY OF SUBSCAPULARIS TENDON AND THE FUNCTIONAL OUTCOME IN GRAMMONT STYLE RSA

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INTRODUCTION

Subscapularis tendon management plays an important role in shoulder arthroplasty. An intact subscapularis has been shown to improve functional outcome in patients with anatomic shoulder arthroplasty.2,3,4,10 However, can we extrapolate and expect the similar results in reverse shoulder arthroplasty? Reverse shoulder arthroplasty has a completely different biomechanical design features that influence the function of the prosthesis. The information in the scientific literature regarding the role of subscapularis repair in reverse shoulder arthroplasty, has been variable so far. A few authors have shown that there was no difference in the functional outcome, range of motion and complication rate between patients with and without subscapularis repair.8,9,11,13,14 One study had shown that there was a difference in the functional outcome of the patients with and without subscapularis repair.12 However, not many authors have assessed the post-operative integrity of the subscapularis repair in reverse shoulder arthroplasty. We postulated that a non-healed or ruptured subscapularis would function as non-repaired tendon and would negatively influence the outcome. This could be the reason for the similar functional outcome between patients with repaired and non-repaired subscapularis tendon. Hence, in the present study, we aimed to assess the post-operative integrity of subscapularis tendon in patients who had undergone subscapularis repair after Grammont style reverse shoulder arthroplasty. We also wanted to seek the relationship between the subscapularis tendon integrity and the functional outcome with special attention to internal rotation. We hypothesized that an intact subscapularis tendon would result in better functional outcome and internal rotation after a Grammont style reverse shoulder arthroplasty.

METHOD

This was a retrospective review of all the patients undergone reverse shoulder arthroplasty in our centre from with minimum follow-up of 2 years. The inclusion criteria were primary reverse shoulder arthroplasty done for rotator cuff arthropathy, massive irreparable rotator cuff tear and primary osteoarthritis with B2 glenoid, with repaired subscapularis tendon. Deltopectoral approach was used in all the patients with subscapularis midsubstance tenotomy. All the patients undergone bony increased offset reverse shoulder arthroplasty (BIO-RSA) with Grammont style prostheses with 155 degrees of insert neck-shaft angle, 20 degrees humeral retroversion and 36mm glenosphere. The subscapularis tendon was repaired with transosseous sutures. Post-operatively, the shoulders were immobilised with internal rotation brace. Post-operative ultrasound examination was done at 6 months after surgery. Two radiologists experienced in post-operative rotator cuff integrity ultrasound assessment were involved in the study. They were blinded of the functional outcome scores. We classified the subscapularis tendon integrity according to Sugaya classification.6 Type 1, 2 and 3 were considered intact tendon, and type 4 and 5 considered as ruptured tendon. The patients were divided into 2 groups: intact and ruptured tendon. Post-operative Constant score was assessed and compared between the two groups. A separate analysis was done for the internal rotation component in the Constant score.

RESULTS

In total, there were 100 patients fulfilling the inclusion criteria. Sixteen patients were excluded as 5 patients had deceased, 4 patients lost to follow-up, 3 patients refused to participate and 1 patient undergone latissimus dorsi transfer. The remaining 86 patients, consisted of 53 men and 33 women, had mean age 73 years and average follow-up 3.3 years.

Post-operative ultrasound assessment revealed that 59 patients had healed subscapularis tendon (Sugaya type 1, 2 or 3) and 27 patients had ruptured tendon (Sugaya type 4 or 5). The rupture rate was 31%.

Post-operative Constant score assessment showed that the mean score for healed subscapularis tendon group

was 74 and the mean for ruptured tendon group was 71. The difference was statistically significant (p<0.005). The mean internal rotation score was 7.2 in healed subscapularis group and 5.1 in ruptured tendon group (p<0.005)..

DISCUSSION

Sugaya et al introduced a classification system to assess integrity of rotator cuff tendon after repair.6 The classification is divided into five types based on the appearance of the repaired tendon in the MRI scan. Although originally it was created based on MRI scan, Collin et al had shown that ultrasound assessment of post-operative integrity of rotator cuff tendon according to Sugaya classification demonstrated good sensitivity and specificity, in addition to good inter-observer agreement.7 Despite being operator dependent and less accurate with small tears, ultrasound is the best modality we have to assess tendon integrity after shoulder arthroplasty. Alternatives such as CT scan and MRI have issues with accuracy in assessing tendon healing due to image artefacts produced by the prostheses. Ultrasound had been used in the past by many authors to assess the subscapularis tendon integrity after anatomic total shoulder arthroplasty.1,2,3,4,5 Recently, there were publications reporting on the usage of ultrasound in assessing subscapularis tendon after reverse shoulder arthroplasty.8,9 The classification of tendon integrity used in these studies had been variable. De Boer et al used ultrasound to assess 65 shoulders (25 – subscapularis tendon repaired, 40 - not repaired) and classified the tendon integrity as intact and not intact.8 Dedy et al described tendon integrity as intact, attenuated, or absent.9 The attenuated group was further subdivided into mild attenuation (ie, tendons with minimal or no thinning but a hypoechoic signal) and severe attenuation (ie, thinning of >50% compared with a normal rotator cuff tendon). A ruptured tendon was defined as a tendon that could not be visualized with dynamic examination or had a visible defect with retraction of the proximal tendon or muscle belly. In the present study, we used ultrasound to assess the subscapularis tendon integrity after reverse shoulder arthroplasty and evaluated the tendon using Sugaya classification. Sugaya classification has been a standard evaluation of post-operative rotator cuff tendon integrity and had been validated for ultrasound.7 We used Sugaya classification for these reasons, convinced that it would give us a standard and reproducible method of evaluation. In our assessment, we considered type 1, 2 and 3 as continuous tendon and type 4 and 5 as ruptured tendon.

Many authors had shown the importance of subscapularis repair in anatomic total shoulder arthroplasty 2,3,4,10. Contrarily, the role of subscapularis repair in reverse shoulder arthroplasty has been a controversial issue. A search in current literature revealed studies with variable results and conclusion. Boulahia et al examined 18 shoulders with Delta reverse shoulder prosthesis and found that the functional outcome was not affected by subscapularis repair.14 Clark et al investigated the effect of subscapularis repair on post-operative complication, pain and range of motion.13 They compared 65 shoulders with repaired subscapularis against non-repaired 55 shoulders. The authors found that there was no difference between the two groups in terms of complication, pain and range of motion. However, the authors did not use any functional outcome scores and assess the post-operative integrity of subscapularis tendon. Besides, 60% of the cohort involved acute fractures, fracture sequelae and revisions. Vourazeris et al compared 86 shoulders with repaired subscapularis and 116 non-repaired shoulders.11 The authors found that there were no significant differences in the outcome scores, strength, range of motion and complication rate. However, the authors did not assess the post-operative integrity of the subscapularis repair. Friedman et al compared functional outcome between patients undergone reverse total shoulder arthroplasty with and without subscapularis repair (340 repaired vs 252 not repaired).12 Their study revealed that the repaired group had significantly higher post-operative outcome scores (ASES and UCLA) (Friedman). Similar to other studies, there was no assessment of post-operative integrity of subscapularis tendon.

Assessment of post-operative integrity of subscapularis tendon repair is an important aspect in analyzing the role of subscapularis in reverse total shoulder arthroplasty. A non-healed or ruptured tendon would function as non-repaired tendon and influence the outcome. Recently, F.A.de Boer et al analyzed 65 shoulders in patients undergone reverse shoulder arthroplasty.8 Twenty-five shoulders had subscapularis reattached and 40 shoulders had insufficient subscapularis not suitable for repair. Post-operative ultrasound assessment showed 60% ruptured tendon in the repaired group. There were no significant differences in functional outcome scores (Constant and Oxford shoulder score), strength, range of motion and pain between the groups. Dedy et al examined 48 shoulders undergone reverse shoulder arthroplasty.9 Post-operative ultrasound assessment revealed 6 shoulders with intact tendon, 16 intact with mild attenuation, 15 severe attenuation and 11 not intact or absent. The classification was further simplified into intact (intact and intact with mild attenuation) and not intact (severe attenuation and not intact). Therefore, the rupture rate was 54.2%. They found no significant differences in DASH, Constant and Oxford scores between groups but higher internal rotation in the intact group. In the present study, post-operative integrity of subscapularis tendon was done by experienced radiologists and the rupture rate was 31%. We compared the mean Constant score between the patients with healed subscapularis tendon and ruptured tendon; and found that the mean Constant score and the internal rotation score was significantly higher in the healed tendon group. The strength of the study was in its uniform surgical factors. It was a single centre study with all the cases done by a single surgeon. The surgical technique – deltopectoral approach, subscapularis midsubstance tenotomy and repair of the tendon using transosseous sutures – was similar in all the patients. A single type of implant – Grammont style prosthesis with 155 degrees neck shaft angle, 36 mm glenosphere and 20 degrees humeral retroversion – was implanted in all the patients. With this uniformity, we could exclude variability in the study to get a comparable result. Second, the ultrasound assessment was done by radiologist who were blinded to the functional outcome of the patients. Third, the standard and validated Sugaya classification was used to assess the post-operative tendon integrity. Fourth, the study had substantial number of patients (86 patients) with long follow-up (mean folow-up 3.3 years).

The limitation of the study lies in the fact that it was a single centre study and all the cases were done by a single surgeon. The findings lacked the potential for generalization. Besides, this study lacked the pre-operative data for Constant score. Differences in the pre-operative and post-operative outcome score could not be evaluated and compared in between the groups.

CONCLUSION

The healing rate of subscapularis tendon after reverse shoulder arthroplasty in the present study was 69%. The Constant score and internal rotation in the patients with healed subscapularis tendon after Grammont style reverse shoulder arthroplasty was significantly higher than in the patients with ruptured tendon.

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35/ WHY I CHOOSE A CONVERTIBLE HUMERAL COMPONENT IN ANATOMIC TOTAL SHOULDER ARTHROPLASTY

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INTRODUCTION

The volume of shoulder arthroplasty procedures performed in the United States has increased substantially over the past decades, from 14,000 shoulder hemiarthroplasty (HA) and total shoulder arthroplasty (TSA) procedures performed in 2000 to over 46,000 performed in 2008, an increase of nearly 12% per year.[1] If this trend continues, an estimated 100,000 shoulder arthroplasties will be performed annually this year. 2 While at least part of these increases are due to an aging population that desires to remain active, a large percentage of this increase is due to rising popularity of and expanding indications for reverse total shoulder arthroplasty (RTSA).[3]

Accompanying this exponential increase in primary shoulder arthroplasty is an expected increase in the incidence of revision shoulder arthroplasty. The estimated rate of revision for failed shoulder arthroplasties has grown by 400% over the last twenty years, making revisions account for up to 10% of all shoulder arthroplasty. 4-6 Revision shoulder arthroplasty is most often indicated for multiple modes of failure including glenoid component loosening, instability and rotator cuff failure. Revision arthroplasty can be significantly more challenging than the index procedure due to the frequent need for component removal, which can lead to bone loss.[7]

Recently, due to success of reverse total shoulder arthroplasty for rotator cuff tear arthropathy, the indications have expanded to use of this procedure as a revision option or salvage for failed prior arthroplasty, including revision of failed shoulder hemiarthroplasty or failed anatomic shoulder arthroplasty.[8, 9] Conversion of prior arthroplasty to a reverse shoulder arthroplasty can be technically demanding and fraught with complications. These challenges led to the recent introduction of a platform system for shoulder arthroplasty, which can include a convertible modular humeral stem and/or a metal-backed glenoid component to facilitate straightforward conversion from either a hemiarthroplasty or anatomic total shoulder arthroplasty (ATSA) to a RTSA without any revision to the stem or glenoid baseplate.[10]

In this chapter we will focus on why we use of convertible humeral component system wherever possible in primary anatomic TSA, HA and HA for fracture.

Uses and Advantages of a Platform Humeral Convertible System

A platform system for shoulder arthroplasty offers system flexibility and interchangeability for subsequent revision surgery. This would allow, in theory, for less demanding and time consuming revision surgery, and potentially reduce complications associated with the removal of a well-fixed humeral stem component.

Humeral Stem in a Platform System for Shoulder Arthroplasty

Conversion of a traditional HA or ATSA to RTSA requires the removal and reimplantation of a humeral stem. As humeral stem loosening is exceedingly rare due to complete integration with host bone, humeral shaft corticotomy is often required for stem removal, which is associated with a high rate of fracture.[11, 12] Additional fracture risk may rise from cerclage wire fixation which may be required to stabilize diaphyseal osteotomies or from diaphyseal perforation of the revision stem. One recent study noted a 21% intraoperative humeral shaft or tuberosity fracture rate during stem removal during conversion to RTSA.[13] Other studies have noted humeral fracture rates of up to 25% during stem removal at revision.[10, 12, 14, 15] Additional risks of humeral stem removal include potential loss of humeral bone stock, nerve injury, periprosthetic fracture, and malunion or nonunion of a humeral osteotomy with later humeral component loosening.[11, 14, 16, 17]

The use of a platform system allows conversion of a hemiarthroplasty or ATSA to RTSA without removal of the humeral stem. Compared to patients in which stem removal is required, this virtually eliminates the risk of intraoperative humeral fracture. A recent study reported a 0% rate of humeral tuberosity or shaft fractures in patients with platform humeral stems converted to RTSA.[13] A similar study of 26 patients with full modular stems likewise reported no intraoperative humeral complications.[18]

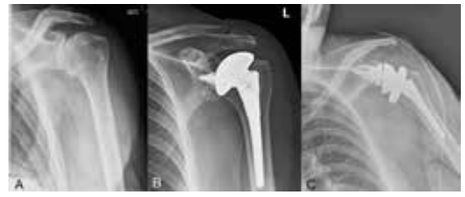

Figure 1
A 72 year-old female with left shoulder pain due to osteoarthritis (A) underwent anatomic total shoulder arthroplasty using a convertible humeral stem (B). She later fell and suffered a subscapularis rupture, which failed primary repair. She was later converted to an RTSA, maintaining her previous stem, with an excellent functional result (C)

Clinical Outcomes using Humeral Platform Systems

As platform systems are a relatively new advent in the evolution of shoulder arthroplasty design, only limited case series exist describing clinical outcomes utilizing such technology. Castagna, et al recently published a series of 26 patients who underwent conversion of a previous shoulder arthroplasty to an RTSA using a platform system.[18] The index operation in 18 of the patients was hemiarthroplasty for fracture; the remaining 8 patients had an ATSA for glenohumeral arthritis. The authors reported that the use of a fully modular system allowed avoidance of humeral stem removal in all patients, and the metal-back glenoid in revision of ATSA, resulting in a short operative time and few intraoperative complications. At an average of 32 months follow-up, the average constant score improved from 25 points to 48 points, while the EuroQol Visual Analog Scale (EQ-VAS) improved from 40 preoperatively to 70 postoperatively. All patients improved in terms of range of motion and follow-up imaging obtained at final follow-up demonstrated good integration of the implants without any evidence of loosening.[18]

A recent study published by Wieser, et al evaluated outcomes in 48 patients with hemiarthroplasties and eight patients with ATSA converted to RTSA with (n = 43) and without (n = 13) stem exchange to elucidate potential advantages of a platform system.[17] The authors found significantly shorter surgical time and lower average blood loss in patients without stem exchange. Intraoperative complications were also significantly lower in patients without stem exchange (8%) compared to patients with stem exchange (30%). Clinical outcomes were assessed in patients who did not have intraoperative complications. Average Constant scores improved from 30 to 48 in the stem-retaining group, which was not significantly different from the stem-removal group (in patients without intraoperative complications), who had an improvement from 24 to 45.[17] Although these results are promising, several limitations of this study should be noted. The average time to revision of the index shoulder arthroplasty was only 38 months, which is quite short and raises the question of component malposition as an etiology for many of the revisions included in the study. Furthermore, the authors state that improper placement of the initial stem may preclude retention; this idea is supported by the fact that one third of the shoulders underwent removal of a modular stem, and those patients who underwent exchange of a modular stem often required subsequent surgery.[17]

Kany, et al recently reported their experience with a platform shoulder arthroplasty system in 29 patients, including five hemiarthroplasties, eight ATSA with cemented glenoid components and 16 ATSA with metal-backed glenoid components.[10] Of these, three ATSA with cemented glenoids were converted to ATSA with metal-backed glenoids, and the remainder of the included arthroplasties were converted to RTSA. The authors found that the humeral stem could be maintained in 72% of patients, with the remaining patients requiring stem change due to a high position of the index humeral stem component which prevented reduction of the new RTSA. Corticotomy or humeral shaft windows were not required for stem removal. Only two metal-backed glenoid components required exchange during conversion from ATSA to RTSA, both due to loosening in the setting of Walch type B2 glenoid bone wear. Clinically, patients demonstrated significant improvement, from an average preoperative Contstant score of 27 to 60 postoperatively. At a mean follow-up of 28 months, no radiological glenoid or stem loosening was noted.[10]

Limitations and Complications Associated with Platform Systems

While designed to reduce intraoperative complications such as blood loss, humeral fracture and glenoid bone loss due to the time and effort involved in component removal during revision shoulder arthroplasty, platform systems have associated limitations and complications that require mention. When choosing to maintain a convertible humeral prosthetic stem, the surgeon must accept the position of the stem, which is certainly a limitation if the position is suboptimal.[9] Care must be taken at the index operation to utilize meticulous surgical technique to appropriately position the stem, not only to improve the longevity of the index implant, but to allow for revision without any need for stem removal. Based on existing studies, even when presumably good surgical technique is utilized, it is possible that removal of a convertible stem may be required at the time of revision to appropriately reduce the revision prosthesis and achieve adequate soft tissue tension in 25% of cases.

Onlay humeral platform components allow for a more direct conversion from an ATSA to an RTSA. Once the humeral head component is disengaged from the stem, the reverse humeral tray can be inserted directly onto the hu-

meral stem without the need for additional reaming of the proximal humeral metaphysis. Most systems have humeral trays with several different offsets and thicknesses, which can be combined with polyethylene liners of various thicknesses to optimize the stability of the implant while minimizing impingement. The ability to adjust humeral length and version may be more limited with these Onlay components. For humeral stems that are malpositioned too proximally, the resulting humeral length and deltoid tension created by the thickness of the humeral tray and polyethylene may preclude stem retention. Overtensioning the deltoid can have deleterious consequences as this results in increased load on the glenosphere and scapular spine, which potentially may result in glenoid component loosening and fatigue fractures of the acromion/ scapular spine. Similarly, the humeral version is dictated by the position of the anatomic stem. While some systems have the capacity to adjust the humeral version to a certain degree by modifying the humeral tray. However, this modest adjustment may not be sufficient in cases of excessive retroversion. If the height or version preclude a simple conversion, the anatomic stem needs to be removed.

Inlay prostheses require additional humeral preparation to convert from an ATSA to an RTSA; however, ultimately they have more versatility compared to Onlay components. After removal of the humeral head, the modular body needs to be removed. We prefer to use a flexible osteotome to separate any bony ingrowth between the body of the humeral stem and the proximal humeral metaphysis. Flexible osteotomes are thinner and more maneuverable, ultimately allowing more of the proximal humeral bone stock to be preserved. This step is critical for cemented as well as uncemented components as circumferential separation of the body from the humerus is necessary for safe component removal. Following removal of the modular body, the overall position of the humeral component needs to be assessed prior to preparing the proximal humeral metaphysis for the reverse body component. If the humeral component is malpositioned too proximally, one can address this in one of two ways: additional resection of the proximal humerus or by adjusting the height of the modular body component. One of the unique benefits of the Inlay system is that additional humeral resection can be performed without interfering with the well-fixed stem distally. Another benefit of the Inlay prosthesis is that the modular body for the RTSA can be reoriented and therefore is not limited by the humeral version from the index procedure.

Current Commercially Available Platform Systems in the United States

Manufacturer/Name	HA Option?	ATSA Option?	RTSA Option?
Depuy Global Unite	Yes	Yes	Yes
Exactetch Equinoxe	Yes	Yes	Yes
Tornier Aequalis Ascend Flex	No	Yes	Yes
Integra Titan	Yes	Yes	Yes
Smith & Nephew PROMOS	Yes	Yes	Yes
Zimmer Biomet Comprehensive	Yes	Yes	Yes

CONCLUSIONS

Platform systems in shoulder arthroplasty offer significant versatility and numerous advantages, particularly in the revision setting, by decreasing the amount of surgical exposure needed during revision surgery, often eliminating the need for humeral osteotomy and thus reducing the incidence of intraoperative humeral fractures, decreasing surgical time, decreasing blood loss and decreasing overall complications during conversion from previous arthroplasty.

Even with a convertible platform humeral component system 25% of cases will require removal of the stem due to component position in height and version at the index procedure.

Convertible humeral component platform options offer significant advantages in revision surgery when possible. It is for this reason that I always choose a convertible platform system in primary shoulder Arthroplasty procedure when possible.

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36/ PRIMARY SHOULDER ARTHROPLASTY UNDER AGE OF 60 Y.O. - FACTORS OF SURVIVAL PF 1332 CASES WITH A MINIMUM FOLLOW UP OF 2 YEARS

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INTRODUCTION

Because of rather satisfactory results, there has a trend for shoulder arthroplasty to be performed in younger patients, but the long-term outcomes of these patients remain limited.[1, 2, 3, 4] These patients are more active and can be expected to practice sport or to use their shoulder more vigorously. Specifically, patients undergoing shoulder arthroplasty have been shown to remain quite active. McCarty et al[5] has showed that 64% of patients undergoing shoulder arthroplasty returned to sporting activities. So, the risk of arthroplasty failure or revision in the long term is high.
However, the survival rate can be different regarding etiology and type of arthroplasty. In a series of patients under 50 y.o., with a FU of 20 years, Schoch and al.[6] has showed that estimated 20-year survival was 75.6% for hemi and 83.2% for TSA and that there was a significant difference regarding the survival rate between rheumatoid arthritis and sequelae (89% at 20 years versus and 64.9%). A preoperative diagnosis of post-traumatic arthritis was associated with an increased risk of revision during the length of the study. Because of a too small number of patients in other groups, he was not able to analyze other etiologies. Regarding RSA in patients under 60 y.o., Ernstbrunner and al.[7] reported a survival rate of revision which was 96% at 5 years and 92% at 10 years.

We therefore carried out a study with two goals:
- to evaluate shoulder arthroplasties after more than 2 years of follow up with survival curves to prosthetic revision, and
- to analyze the effects of preoperative aetiology on those outcomes.

Our hypothesis is that, both aetiology and type of arthroplasty are the main parameters which influence the revision rate.

MATERIAL AND METHODS

Between 1995 and 2015, 1332 primary shoulder arthroplasties (RSA) were implanted in 1046 patients (143 bilateral cases) in 9 orthopaedic centres. There were 47.4% of women and 52.6% of men. Mean age at the time of surgery was 51.1 years (range, 19 to 60 years). The distribution of the arthroplasty according to aetiology is reported in table 1.

	Hemi Arthroplasty	RSA	TSA	Total
Acute fracture	104	1	0	105
Aseptic Osteonecrosis	108	0	19	127
Cuff Tear Arthropathy (Hamada 4,5)	6	24	4	34
Fracture sequelae	150	48	71	269
Instability Arthropathy	79	13	68	160
Massive Cuff Tear (Hamada 1,2,3)	1	45	3	49
Other diagnosis	27	7	7	41
Primary OA	100	12	265	377
Rheumatoid Arthritis	39	20	67	126
Tumor	7	26	1	34
Total	**621**	**196**	**505**	**1322**

Table 1
Distribution of arthroplasty according to aetiology.

We have analysed complications, reoperations (without implant exchange excepted insert) and revisions (with implant exchange or removal).
Survival curves were established with the Kaplan-Meier technique and with 95 per cent confidence intervals according to Rothman. One endpoint was retained:
- implant replacement, whatever the reason
Survival curves were segmented according to aetiology or to the type of arthroplasty to seek significant differences. Comparisons of instantaneous survivorship were carried out with the log-rank test.

RESULTS

At review, 27 patients had died before 2 years follow up. One hundred and sixty-three were lost of follow up or bedridden or have refused to come. Two hundred have been revised, 47 before 2 years follow up and 153 after (Fig. 1).

Figure 1
Flow chart of the population

So, 932 shoulders were available for an assessment with a minimum FU of 2 years. For deceased patients, information on the prosthesis was obtained either from medical records or by phone from the patient's family. Mean follow-up was 96 months (range, 24 to 310 months). Mean age at review was 59.1 years (range, 22 to 81 years).
There were 361 complications. A reoperation was necessary in 52 cases and a revision in 200 cases (out of 20 had had a reoperation before).
The survival curve to revision showed a global survivorship of 91.4 per cent at 5 years, 81.7% at 10 years and 68.4% at 15 years (Fig 2).

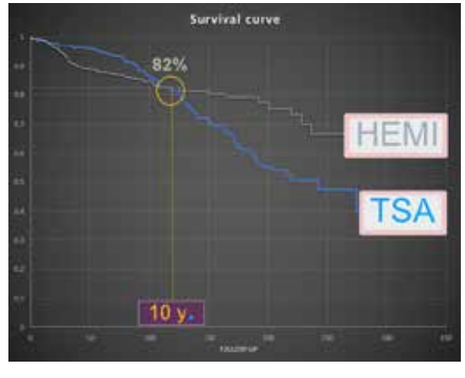

Figure 2
Overall survivorship to revision (Kaplan-Meier method, Rothman's 95% confidence intervals)

There was no difference according to gender or age (< 50 y.o. versus > 50 y.o. at time of surgery).
Regarding the type of arthroplasty, follow up was significantly more important for TSA (Table 2).

	Hemi	RSA	TSA	Total
Acute fracture	82,53	1,28		81,76
Aseptic Osteonecrosis	79,61		77,21	79,25
Cuff Tear Arthropathy (Hamada 4,5)	58,63	65,94	133,32	72,58
Fracture sequelae or Post-traumatic arthritis	75,90	65,07	101,62	80,75
Instability Arthropathy	64,59	53,50	99,79	78,65
Massive Cuff Tear (Hamada 1,2,3)	191,54	53,46	117,96	60,22
Other diagnosis	73,30	80,32	99,55	78,98
Primary OA	67,72	30,68	85,60	79,11
Rheumatoid Arthritis	115,22	57,48	135,27	116,72
Tumor	158,53	58,08	59,76	78,81

Table 2
Follow up in months according to aetiology and type of arthroplasty

Segmentation of the curves according to the type of arthroplasty didn't show a significant difference (Table 3).

	5 years	10 years	15 years
HEMI	87.9%	82.8%	79.2%
TSA	94.8%	82%	61.4%
RSA	93.9%	81.6%	72.5%

Table 3
Survival rate according to type of arthroplasty

At 5 and 10 years, there is no significant difference regarding the survival rate. However the shape of the curves between hemi and TSA is different. For hemi there is a break during the first 3 years and then the curve becomes stable. For TSA, the break is after 5 years (Figure 3).

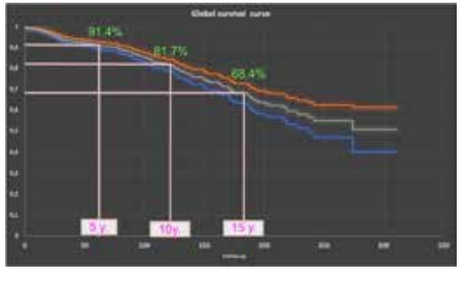

Figure 3
Overall survivorship to revision according to type of arthroplasty (TSA versus HA) (Kaplan-Meier method)

At 10 years, the curves cross then the rate of revision becomes low for hemi and is growing up for TSA. If we do the analysis without tumors and others aetiologies, the survival rate of RSA at 10 years, becomes significantly better ($p<0.05$)y than that of TSA and hemi (91% for RSA versus 82% for TSA and hemi).
Segmentation of the curves according to the aetiology showed a significant difference (Table 4). Massive cuff tear (MCT) group has the best survival rate and tumor group the worst one.

	5 ans	10 ans	15 ans
Global	91.4%	81.7%	68.4%
Acute fracture	87.1%	84.8%	75.9%
Aseptic Osteonecrosis	96.8%	92.1%	84.9%
Fracture sequelae	87.5%	80.7%	66.8%
Instability Arthropathy	93.5%	83.8%	47.6%
Primary OA	90.2%	75.2%	57.8%
Rheumatoid Arthritis	95.3%	87.2%	78.7%
Massive Cuff Tear (Hamada 1,2,3)	100%	100%	100%
Cuff Tear Arthropathy (Hamada 4,5)	96.2%	92.1%	84.9%
Tumor	76.4%	58.8%	44.1%
Other diagnosis	97.5%	84.1%	

Table 4
Survival rate according to aetiology

The shape of curves is very different according to aetiology (Figure 4).

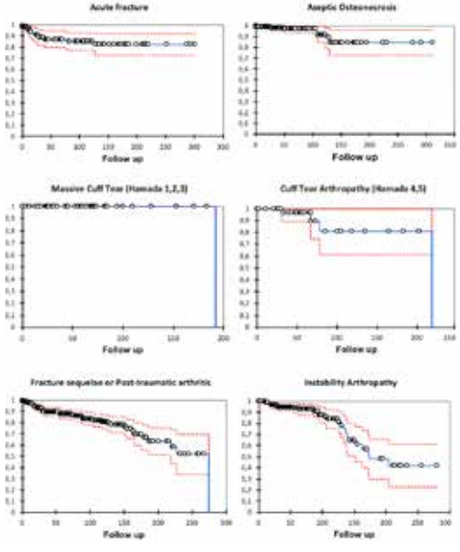

Figure 4
Overall survivorship to revision according to aetiologies (Kaplan-Meier method, Rothman's 95% confidence intervals)

Fractures group has a break in the beginning and then becomes stable.
Avascular necrosis (AVN) curve is flat in the beginning and has a break at 9 years. This is significantly correlated to the type of procedure (TSA versus Hemi) and the reason is glenoid loosening excepted in one case of early revision because of a dislocation.
Cuff tear arthropathy (CTA) curve has a break at 6 years. This was correlated to the type of arthroplasty (3 out 6 hemi had to be revised for a symptomatic glenoid wear and 1 out of 4 TSA for a glenoid loosening). No RSA have been revised.
Fracture Sequelae (FS) curve decreases in the beginning with a break during the first 3 years and after 12 years. There was no difference according to the type of arthroplasty. The main cause of revision for RSA was humeral loosening, for hemi a symptomatic glenoid wear and for TSA a glenoid loosening.
Arthropathy post Instability (AI) curve has a severe break after 10 years. There was no difference according to the type of arthroplasty. The main cause of revision was glenoid problems (loosening for TSA and symptomatic glenoid wear for hemi). In this group, the follow up of TSA was significantly higher (table 2).
MCT curve has no break until 15 years.
Primary osteoarthritis (OA) curve is slowly descending in the beginning, more quickly after 5 years. There was no difference according to type of arthroplasty. The main cause of revision was glenoid problem (loosening for TSA and symptomatic glenoid wear for hemi) and some infections.
Rheumatoid arthritis (RA) curve is slowly descending after 6 years. The main cause is due to TSA group because of glenoid loosening. There is no revision for RSA group but the follow up is less important.
Tumor curve has a severe break after 2 years. This is the worst aetiology regarding survival rate and the main cause were, dislocation, infection and humeral loosening.

DISCUSSION

This study is unique because of the large number of studied shoulders. We have been able to analyse all types of aetiologies and all types of arthroplasties with a minimum follow up of 2 years and a mean follow up of 8 years. Our hypothesis is confirmed. Aetiology and type of arthroplasty are important factors of the survival of prosthesis in this specific patient population under 60 years old.
All groups with a significant number of TSA (OA, AI, FS, AVN, RA) had an important rate of revision after 9 years because of glenoid loosening. Hemi is at risk of pain, stiffness and symptomatic glenoid wear in the beginning. This is an explanation of the break seen during the first 3 years. It's the same for fracture group but the main cause is related to tuberosities problems. However, when the cartilage is intact as for AVN, the survival rate is very good. RSA has a good overall survival rate but the follow up of this group is less important probably because surgeons were afraid to use such an arthroplasty in young patients at the beginning of their experience.
The most important data is the high rate of revision in OA and AI group mainly because of glenoid loosening. This rate is higher than in previous studies[8, 9] In these studies, the survival rate at 10 years is 100% for Kasten[8] and 94.5% for Young[9] Even if the glenoid loosening was frequent after 10 years but only a few have needed a revision. The only difference with our study is the age of the population. This would mean that it is relatively risky to implant a TSA in young population.
Surprisingly, MCT and CTA with a majority of RSA have a rather good survival rate even if the majority of patients have been operated before. Such results have been reported by Ernstbrunner and al.7 with a survival rate 92% at 10 years. Therefore, RSA in young population with a CTA or MCT seems a reasonable indication. Conversely, the few HA implanted in this indication had to be revised. This confirms the previous results of other studies[10, 11]
HA is the indication of choice for AVN with a rate of 92.1% at ten years and is not so bad in rheumatoid arthritis (87.2% at 10 years). Regarding RA, Schoch and al.[7] reported similar results. However we notice that RSA have also a good survival in this aetiology.
Lastly, FS is clearly difficult to manage. The break at the beginning is mainly due to pain and stiffness with HA. The break after 10 years is due to glenoid loosening with TSA. Moreover, in this aetiology, RSA is at risk of humeral loosening probably because of bone defect in the metaphyseal area making the fixation of the stem only distal. It is the same problem for tumors.

CONCLUSION

In conclusion, our study with a minimum follow-up of 2 years but a mean follow up of 8 years leads to the following recommendations for this young population :
- RSA is indicated for CTA, and MCT even in case of previous surgery.
- HA must be implanted in AVN and fractures and could be used a little bit more in RA, AI and OA instead of TSA. Extreme care must be taken to prevent late glenoid loosening which is the main complication and makes revision difficult.
- FS is the most difficult aetiology to address.
- Tumor is at a very high risk of revision but often there is no other choice.

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37/ CLINICAL AND RADIOLOGICAL LONG TERM RESULTS OF REVERSE STEMLESS PROSTHESES

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INTRODUCTION

Cuff tear arthropathy is a challenging situation. Since the revolution from Paul Grammont (1,2), RSAs achieve good functionnal outcomes (3). The results are gradually improving with the new prosthesis designs and the surgical evolutions. Nevertheless, we will have to deal with revisions because of the rate of complication (4), the lifetime and the number of reverse surgeries. RSAs need to be as less invasive as possible to preserve the bone stock. We use stemless RASs for more than 10 years with the TESS. This presentation is the report of the results with more than 10 years FU.

MATERIAL AND METHODS

This prospective study included 53 stemless reverse prostheses (TESSi) in 53 patients, performed by the same surgeon between 2006 and 2008. Fourteen patients died from another cause than the shoulder.
At the end, 28 stemless TESSi were reviewed, 15 men and 13 women ; the mean age was 76 years (54-85) at the time of the surgery; The mean FU was 129 months.
Indications were CTA stage 3 in 14 cases, stage 4-5 in 11 cases according to Hamada classification (5), and 3 cases of malunion with rotator cuff tear. In these cases, 12 were prior failed rotator cuff repairs
The patients provided informed consent for their data to be included in the study.

TESS design (fig.1)

The TESS is a system which allows to perform HAs, TSAs and RSAs. This was the first stemless prothesis, avalaible in both anatomical and reverse configuration. The stem is always an option.
For the RSA, the design was based on Grammont's concept, and Inlay. The glenoid baseplate is uncemented and is secured by a full hydroxyapatite central peg with titanium plasma spray, as well as 4 locked screws. The glenosphere (size 36 or 41 mm in diameter) is eccentric, with a 3-mm lateralization. The humeral implant is based on the Reverse corolla RCo, which is an uncemented metaphysealepiphyseal implant made of chrome cobalt, with a titanium plasma spray and full hydroxyapatite coating, available in 4 sizes. Six wings on the surface of the RCo optimize the rotational stability. The polyethylene component is available in 4 thicknesses.

Figure 1
TESS System

Operative technique (fig. 2 and 3)

At the time, the procedure was performed by a superolateral approach, A deltopectoral approach was chosen for concomitant latissimus dorsi transfer in 2 cases of negative and deficient preoperative active external rotation. The humerus was cut with a 150 centromedullary guide. The reamer was cannulated on a pin inn the middle of the humeral cut. The RCo was retroverted by 20 and was uncemented and without a stem. On the glenoid, the baseplate was placed quite inferiorly, but without a tilt.
In all cases, the limb was immobilized on a 45° abduction splint for 3 weeks. Passive range of motion started on day 1 postoperatively, and active range of motion started at 3 weeks postoperatively.

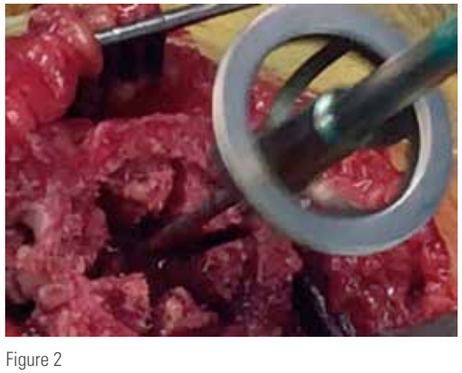

Figure 2
Operative technique : reamer

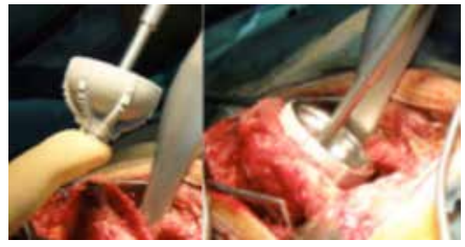

Figure 3
TESSi : reverse corolla (inlay)

Assessment

Clinical assessment, including visual analog pain scores; range of motion; strength in flexion; and a functional assessment with the Constant score (CS) (6), was performed preoperatively and at the last FU. A determination of patient satisfaction completed the clinical analysis.

The radiographic protocol (fig.4) included standardized, fluoroscopically controlled, anteroposterior radiographs in neutral rotation and adduction views, 1 tangential to the baseplate and 1 tangential to the RCo, as well as a lateral view. We measured glenoid inclination, the NSA, glenometaphyseal (GM) angulation, lateralization, and lowering using Osirix software (UCLA, Geneva, Switzerland). Scapular inferior notching was recorded according to the classification of Sirveaux et al. Radiolucent lines were assessed in 5 glenoid and 5 humeral zones areas (fig. 5).

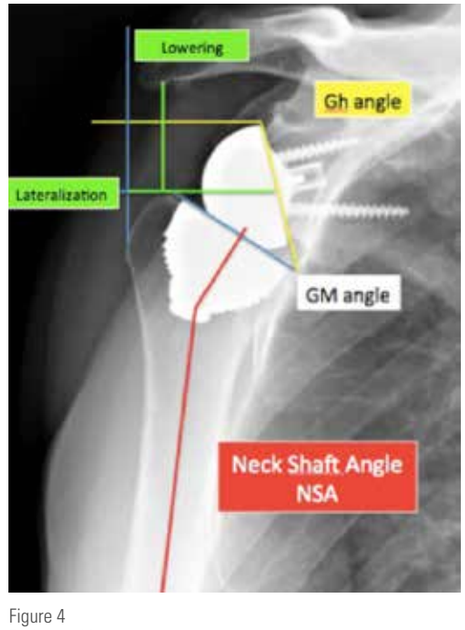

Figure 4
Radiographic measurements

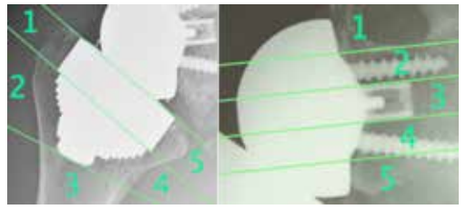

Figure 5

Stemless corollas, were specially studied, with 2 citeria, rocking and subsidence, on a superposition of initial and last X-rays.

Statistical analysis

Analysis of variance with a multivariate analysis plus the Wilcoxon signed rank test (for comparison of specific values obtained postoperatively and at last follow-up), the Mann-Whitney U test (for analysis of differences between 2 subgroups), and the Kruskal-Wallis test (for analysis among several subgroups) was used to analyze the data. $P < .05$ was considered significant.

RESULTS

We report no revision at the end. Ninety-two percent of patients were satisfied or very satisfied. The mean CS was 71 points. All the parameters improved significantly, except the IR.
Complications occurred in 2 patients. One patient who presented with recurrent dislocations was initially reoperated on successfully with the addition of a 6-mm polyethylene spacer. A stress fracture of the spine of the scapula occurred in 1 patient.

No radiographic evidence of glenoid or humeral component loosening was observed.
The mean NSA was 154° (148-160). Rocking was 0,02° (0-5) and subsidence was 0,05 mm (0-1) between post-op and last FU. There was no migration between both FU. Inferior scapular notching was at 46%, with 14 cases at stage 2, and 1 case at stage 3.
For the bone modifications, RLLs were at 100% in zone 1, 72% in zone 5, and very rare in zone 2 and 3. RLLs were correlated to scapular notching (P=.028), increased NSA (P=.048), decreased lateralisation (P=.015). Conversely, bone densifications were observed in zone 4, in all cases, and correlated to vara position (decreased NSA) (P=.032). Notching was correlated to RLLs on humeral and glenoid sides. (Fig.6 and 7)

Figure 6
Bone modifications around the corollas at 10 years FU

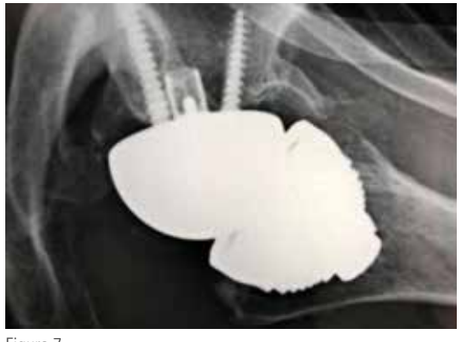

Figure 7
Typical bone resorptions around the RCo, at 6 years FU

DISCUSSION

Cuff deficient shoulder is a challenging situation. The RSA is an invention from Paul Grammont that has revolutionized the treatment of CTAs (1-2). Many published results on Grammont's prosthesis, as well as subsequent RSAs, have shown improvements in pain relief, range of motion, and function (7,8). Even if the rate of complications, higher than 10%, requires vigilance (4). The results of the most recent series are better than those from the first reports, because the improvment of the designs, and the operative technique (9-11), by orienting the metaglene and translating it downwards, and by lateralizing instead of medializing (12).

Because of their lifetime, and the complications. we need to think about the future and their revision, We need to be as less invasive as possible, to save bone stock. In most of cases, the cause of the revision is the glenoid, but the difficulty is on the humerus, to extract the first prosthesis because of the stem, and to reconstruct the humeral bone stock (13-17). Stemless prostheses are called 4th generation (18). The experience started with the TESS group in 2003 for the anatomical and 2005 for the reverse. Stemless prostheses can be extracted without big damage, and revisions use a new stemless or a standard stem, thanks to the diaphyseal bone stock.

For stemless RSAs, there are fewer series which deal with their results, and only short to middle-term results (19-21). All of them used the TESS, and they report the reliability of the corollas, functionnal outcomes are comparable to those published with conventionnal prostheses (19). The first published study did not report any humeral loosening or migration, although there was one intra-operative bone crack without detrimental consequence (22).

This is the first report of long term results with a stemless RSA. Long term results with stemmed prostheses (23-27) are also very good, and our results are equivalent. We found a significant improvment in pain relief, flexion, abduction, and external rotation. The rate of scapular notching, around 60-70%, remains a concern (28,29). Our rate of notching is lower (46%), thanks to the lateralization in the eccentric sphere. The survey is in keeping with the other published series. We observed no humeral loosening despite the lack of a stem. Rocking and subsidence were insignificant. RLLs on the surface is common, and correlated to medialization and valga position. There is no progression to the depth. The absence of RLLs around the corolla (zone 3) confirmed full bone integration.

The trabecular bone densification in zone 4, like a buttress, reflects the favorable bone reaction and adaptation to the loads. These densifications increased in vara position, because of the stress axis. The loads were displaced from diaphyseal when there was a stem, to zone 4 when we used a stem-less system.

The lack of a stem led to interesting findings such as:

- preservation of the metaphyso diaphyseal bone stock, which is interesting for revisions, in case of humeral fracture inder prosthesis.
- better and easier adaptation with anatomic variations, because it deletes constraints from posterior and medial offsets (30,31), which is interesting to make easier all the surgeries, and in cases of mal union, not to need osteotomy of the tuberosity (32).
- variability of positionnement, with the same implant : we just have to change the cut of the humerus. This could be integrated with progresses from computers, the preop plannings, navigations, to perform the prosthesis in an optimal position and combination for each patient (33).

Because the constraints are greater on the humeral side for RSAs, by a rocking-horse phenomena on humerus, this will be necessary to be carreful, and all the new stemless RSAs are not comparable. The TESS is an inlay one, full-hydroxyapathite, and deep enough into the bone. Onlay systems, with screw or cage, will have to be investigated.

CONCLUSION

The TESS stemless RSA is reliable at long FU. Stemless is easier to perform, and will be easier to revise. We recommend to use an inlay stemless RSA.

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38/ MORE THAN 13 YEARS EXPERIENCE WITH THE SHORT STEMLESS METAPHYSEAL RTSA WITHOUT A DIAPHYSEAL STEM - LONG-TERM RESULTS

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INTRODUCTION

Reverse shoulder prostheses are increasingly used in recent years for treatment of glenohumeral arthropathy with deficient rotator cuff such as: rotator cuff arthropathy, rhematoid arthritis, proximal humeral fractures sequelae, irreparable rotator cuff tears, and failed shoulder replacement[39; 42; 48]. Good mid-term and long-term results with restoration of active elevation have been reported[4; 17; 22; 23; 39; 50; 51]. However, early studies showed relatively high rates of complications (24%-50%)[20; 25] and many of these required further surgery[4; 50; 51; 55; 58; 62.] therefore preservation of bone has become a major goal. Metaphyseal cementless implants without a diaphyseal stem have been developed to preserve bone and resect only minimal amount of bone[2; 3; 29; 36; 41; 54].

Currently, the information about the long term clinical and radiological outcomes associated with uncemented metaphyseal reverse TSA is limited[2; 3; 29; 36; 41; 54].

The aim of this prospective study is to report the 5-11 years clinical and radiological results with reverse total shoulder replacement with a novel short metaphyseal humeral design without a diaphyseal stem, discuss the design rationale and determine the safety and complication rate of this design.

MATERIALS AND METHODS

Patients

This prospective study included 159 consecutive patients that underwent cementless press-fit reverse TSA (rTSA) with a novel short metaphyseal humeral design without a diaphyseal stem (Verso, Innovative Design Orthopaedics, London, UK (formerly, Biomet Swindon, UK)) for the treatment of glenohumeral arthropathy with deficient rotator cuff by a single surgeon (OL) in our institution between 2005 and December 2011. At the same period, 26 other patients were treated with stemmed press-fit cementless rTSA (Stemmed Verso, Innovative Design Orthopaedics, London, UK (formerly, Biomet Swindon, UK)) due to acute fractures, surgical neck nonunions and revision of stemmed implant with deficient metaphyseal bone.

The indications for surgery were disabling pain and poor function in patients in whom non-operative treatment had failed. We always try conservative treatment first with the deltoid rehabilitation regime. All patients with indication for rTSA were included. All patients gave informed consent, and the study was approved by the Institutional Review Board and Clinical Quality Assurance office.

Of the 159 patients, 146 were available for long-term follow-up analysis in the short metaphyseal group, and 21 patients of the 26 stemmed Verso prosthesis were available for long term follow-up analysis. The average follow up was 89 months (7 years and 5 months) (range 60 - 138 Months). There were 44 males and 141 females, The mean age at surgery was 74.8y (range 38-93y). 108 patients were operated due to cuff tear arthropathy, 22 for fracture sequelae, 24 for rheumatoid arthritis, 14 patients were after failed RC repair or massive irreparable cuff tear, 3 for osteoarthritis with cuff deficiency or eroded glenoid, 8 for failed anatomical prosthesis with cuff deficiency, and 6 for acute trauma. 14 patients underwent bilateral (staged) rTSA at that period.

50 patients were operated as revision arthroplasty (21 from stemmed implants to stemmed Verso rTSA, 29 to short metaphyseal without a diaphyseal stem rTSA (3 of them from stemmed implant to short metaphyseal without a diaphyseal stem implant).

Description of the implant (Figure 1,2)

The humeral component is a short metaphyseal implant with three tapered thin fins that give immediate metaphyseal press fit fixation when impacted into the cancellous humeral metaphysis with bone graft from the resected humeral head. The implant does not violate the humeral diapysis and does not have a diaphyseal stem. These fins have titanium porous and hydroxyapatite coatings to improve the biologic fixation of the implant. The metaphyseal bone quality or osteoporosis is not a contraindication for the use of this metaphyseal implant, utilising bone graft impaction technique.

The glenoid baseplate has a central tapered screw (hydroxyapatite coated titanium) with the largest core diameter of 9mm and additional 2 anti-rotational screws, superiorly and inferiorly. The glenoid sphere is lateralised 3mm from the glenoid face, this is built in the thickness of the baseplate and the gap between the baseplate and the glenoid sphere. The polyethylene humeral liners have 10º inclined shape, achieved by removing the redundant polyethylene walls inferiorly-medially and respectively on both sides. This provides very low profile medially, that reduces the impingement between the polyethylene liner to the glenoid neck (Figure 1, 2). The humeral cut is performed at 155º angle, with final implant angle of 145º using the inclined liner.

The humeral liners can be dialled in a way that the correct version and offset of the liner can be determined and changed, adapted to each patient even after the definitive metal implants have been implanted.

Figure 1
The Verso short metaphyseal reverse TSA without a diaphyseal stem. The humeral component consists of 3 metaphyseal triple tapered thin fins, the glenoid baseplate consists of tapered central screw and a 10º angled dialable Verso humeral liner

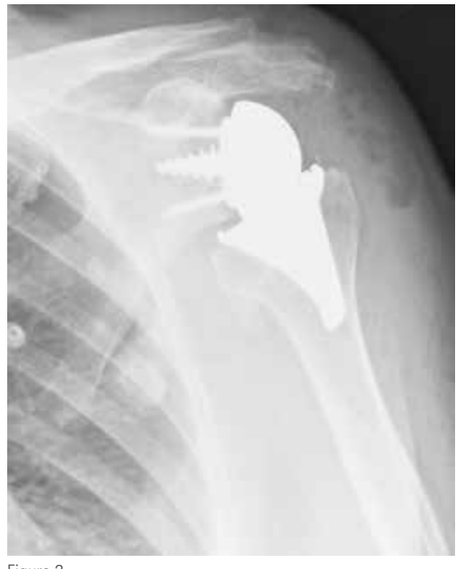


Figure 2
X-rays of the short metaphyseal without a diaphyseal stem reverse prosthesis

Surgical technique

The procedure is performed through the antero-superior approach to the shoulder (Naviaser-MacKenzie approach)[35; 38; 44]. In the revision cases where deltopectoral approach was used in the primary operation, the old skin incision is extended and the antero-superior approach is used subcutaneously[37]. 20mm slice of proximal humeral bone is resected using a guide, in 30º of retroversion. The resected bone is used for bone graft impaction into the humerus. The humeral triple tapered finned component if impacted into the humeral metaphysis. Good initial press fit fixation in conjunction with bone graft impaction technique, was achieved in all patients, regardless of osteoporosis or poor bone quality. The glenoid component is implanted in 10º downward inclination at the inferior border of the glenoid with good initial press fit fixation.

Data was collected prospectively on computerised database. All patients were followed clinically and radiographically. Standardized video recording of range of movements and function was obtained for all the patients preoperatively and at regular intervals after surgery at all the follow-up appointments.

Clinical assessment

Patients demographics including the preoperative diagnosis, previous surgery, and preoperative shoulder function using the Constant Score[7] (pain scores, activities of daily

living (ADL), active range of movement (ROM) and shoulder strength) were obtained. Patient satisfaction was assessed using the Subjective Shoulder Value (SSV21 or SANE59). Operative findings, complications or revision surgery were recorded.

Patients were assessed post-operatively with the Constant score[7; 34], the patient satisfaction score (SSV or SANE score)[21; 34; 59], functional questionnaire regarding return to work, sport and leisure activities[34] and the Video recording at 3 weeks [3, 6, 9, 12, 18, 24] months and yearly thereafter.

Radiographic assessment

All radiographs were assessed by two independent experienced shoulder surgeons.

A true AP view of the shoulder and an axillary view radiographs were critically assessed for displacement, migration or subsidence of the implant, appearance of radiolucent lines, osteolysis, or signs of stress shielding, as well as the Nerot-Sirveaux glenoid notching classification[51]. Bone density was assessed using plain digital radiography in the trabecular bone around the implant as described by Kind et.al[31].

Statistical Methods

Data were collected prospectively and recorded using a dedicated MS Access database. Improvement, or gain, in both functionality (Constant Score) and patient satisfaction assessed by the Subjective Shoulder Value (SSV21 or SANE59) was calculated for each case by comparing the latest observed post-operative value to the corresponding pre-operative value, and the significance of the difference was tested using the paired t-test. Improvement in Constant score was assessed at each time point (pre-op, immediate post-op, 3 weeks then [3,6,9,12] months and annually thereafter.

Statistical analysis was carried out using SAS (Release 8.2 , SAS Institute Inc., Cary, NC, USA, 2001).

RESULTS

At most recent follow-up, patients' satisfaction (SSV) improved from 0.8/10 pre op to 8.2/10 post op following rTSA with this short metaphyseal prosthesis without a diaphyseal stem. 93% felt much better and better at 5-11 years post op in all the diagnoses. 98% felt much better and better (86% excellent) at 5-11 years post op in the cuff arthropathy group. Mean Constant Score (for all diagnoses) improved from 15.6±8.6 preop to 59.0±20.4 at last follow-up. Age/sex adjusted Constant score improved from 22.1±12.3 preoperatively to 86.8±30.3 at the last follow-up (p<0.0001, paired t-test).

No clinical infections observed in this study. Patients were monitored for infection with CRP, ESR, and intraoperative intraarticular specimen collection. The prophylactic antibiotic treatment was withheld until the specimens were collected. Single dose of Teicoplanin and Gentamycin was used for prophylaxis.

For cuff arthropathy patients (n=108) (including 17 cases of revision of resurfacing with cuff deficiency to short metaphyseal Verso without a diaphyseal stem and 11 cases of revision of stemmed implants to stemmed prosthesis). Constant score improved from 15.9±8.3 points to 60.5±19.9 (age/sex adjusted 23.1 to 90.5); fracture sequelae (n=22) from 11.9±8.2 to 49.9±22.8 (age/sex adj. 15.9 to 70.1); Rheumatoid arthritis (n=24) from 13.9±8.2 to 53.5±18.0 (Age and sex adj. 19.2 to 76.0) and the cases of revision of failed arthroplasty with loosening and deficient cuff (n=8) to metaphyseal finned reverse TSA without a diaphyseal stem from 14.7±8.1 to 49.3±24.3 points post-op (age/sex adj. 21.3 to 73.7); Post failed rotator cuff repair or massive cuff tears (n=14) from 23.3±7.3 to 77.1±3.7 (Age and sex adj. 31.4 to 109.4) For acute trauma (n=6) improved to 46.5±18.3 points and 74.0±25.8 age and sex adjusted. All these gains were statistically significant (P<0.0001, Paired t-test, comparing post-op to pre-op)(Figure 3a,b). The Constant score

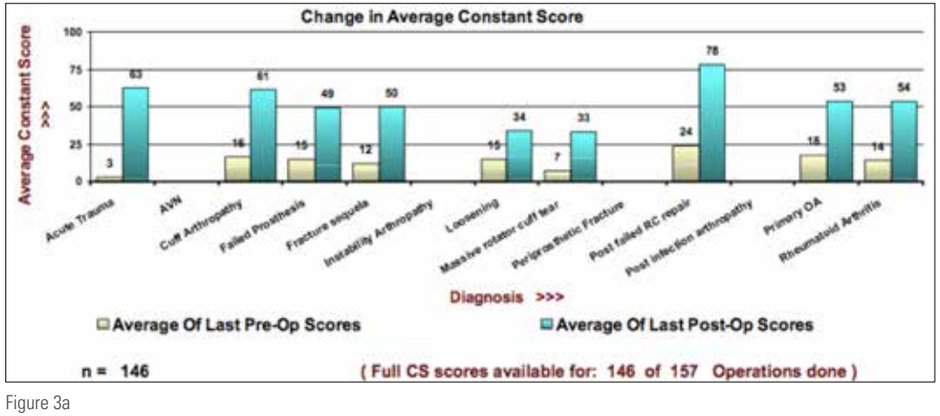


Figure 3a
The preoperative and postoperative follow up Constant scores in different aetiologies (raw score) (P<0.0001, Paired t-test)

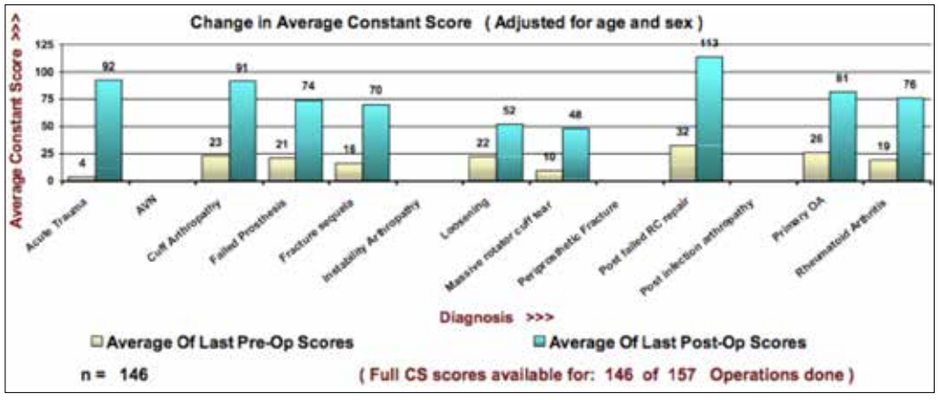


Figure 3b
The preoperative and postoperative follow up Constant scores in different aetiologies (Age & Sex adjusted score) (P<0.0001, Paired t-test)

Figure 4
Improvement of Constant score with time

continued to improve over time in this series (Figure 4).

At most recent follow-up, pain scores were rated mild or none in 161 shoulders (95.8%). The mean VAS pain score (from 0 to 15) decreased from 12 to 2.5. The mean active range of movement improved from 53° to 129.5° elevation, 10° to 50.6° external rotation (in adduction with the arm beside the body) and 24° to 67.2° internal rotation (in abduction) (reaching to the waist with the hand behind the back) (Refer Figure 5, 6, 7, 8). Most patients resumed normal or functional daily and leisure activities according to their reply in the questionnaires34.

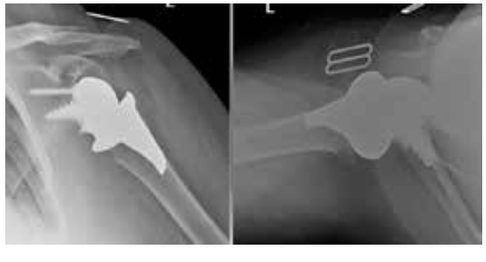
Radiographic analysis

The postoperative radiographic analysis showed no radiolucencies around the humeral or glenoid components, at the latest follow-up. There were no cases of prosthetic humeral or glenoid migration, change in position over time or loosening of the short metaphyseal reverse humeral and the glenoid components. There was no subsidence of the prostheses and no evidence of proximal resorption of bone around the humeral implant to suggest stress shielding. Increased bone density was measured using plain digital radiography in the trabecular bone around the implant[31].

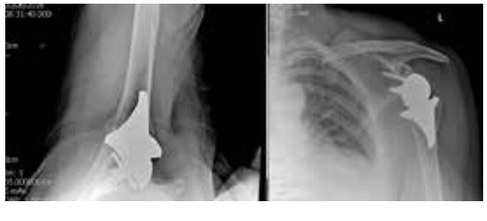
In 38 patients we observed glenoid notching (20.5%), these cases appeared later (>1-2 years) after surgery. 32 of these patients had glenoid notching grade 1 or 2 (Nerot-Sirveaux)[51], and only in 6 cases grade 3 glenoid notching.

A.

B.



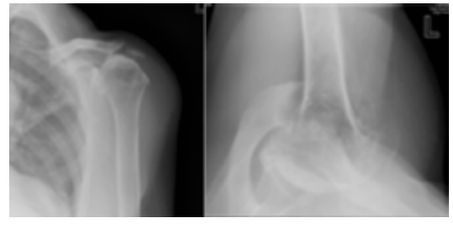
C.



D.

Figure 5
79 years old patient, 9.5 years post revision of left CSRA to short metaphyseal without a diaphyseal stem Verso rTSA:
A. Active range of movement at 9.5 years follow-up
B. Preoperative X-rays with resurfacing of the shoulder
C. X-rays at 2.5 years follow-up after revision to Verso rTSA.
D. X-rays at 9.5 years follow-up after revision to Verso rTSA.

A.



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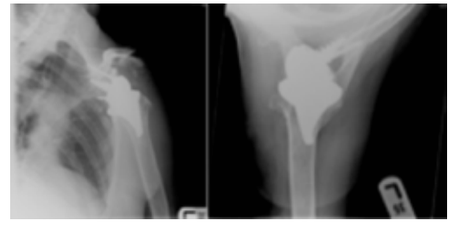

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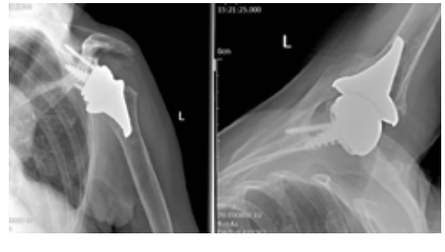
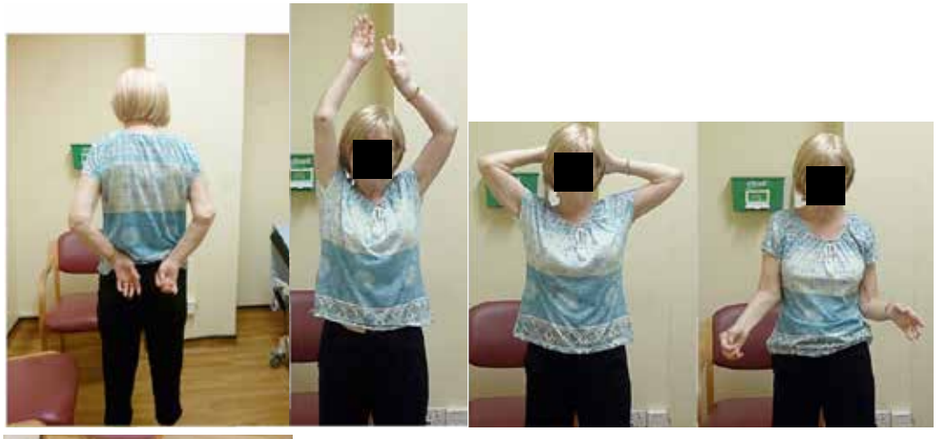
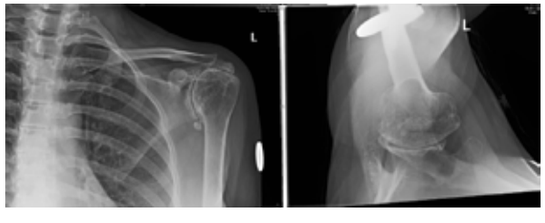


D.

Figure 6
79 years old patient with cuff tear arthropathy, 8 years post left Verso rTSA:
A. Active range of movement at 8 years follow-up
B. Preoperative X-rays with cuff tear arthropathy
C. X-rays 1 month after Verso rTSA
D. X-rays at 8 years follow-up after Verso rTSA



A.



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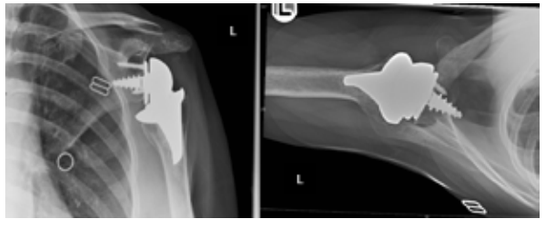

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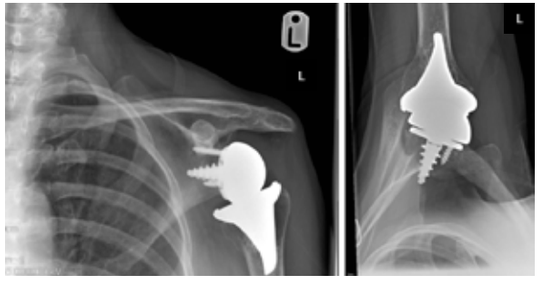
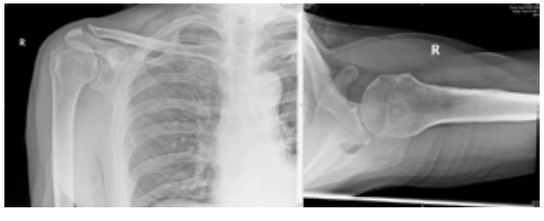


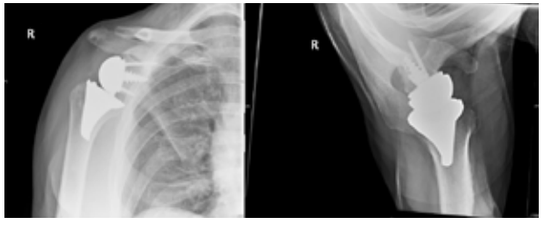
D.

Figure 7
65 years old patient with rheumatoid arthritis,
7 years post left Verso rTSA:
A. Active range of movement at 7 years follow-up
B. Preoperative X-rays with rheumatoid arthritis
C. X-rays 1 year after Verso rTSA
D. X-rays at 7 years follow-up after Verso rTSA

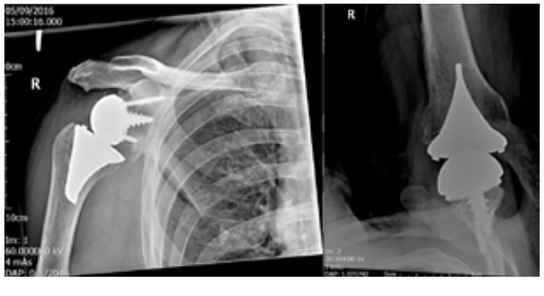
A.



B.



C.



D.

Figure 8
83 years old patient with cuff tear arthropathy,
7 years post right Verso rTSA:
A. Active range of movement at 7 years follow-up
B. Preoperative X-rays with cuff tear arthropathy
C. X-rays 3 months after Verso rTSA
D. X-rays at 7 years follow-up after Verso rTSA

Complications

Two cases had an undisplaced fracture of the humeral metaphysis due to excessive bone impaction in very soft bone and one glenoid rim was cracked during preparation. These were in revision cases. These healed around the implants at three months with conservative treatment. They did not show any lucencies or loosening at the follow-up.

No patient suffered infection and there were no other intra-operative complications.

There were 3 early dislocations; one due to wrong liner version and the patient putting weight on his shoulder in extension of the shoulder (to push himself out of chair) one week post surgery. The others, due to an inferior osteophyte that hinged the liner to dislocate. All were re-operated the osteophyte removed and the liners realigned and made a remarkable recovery.

In one patient, early in the series, the glenoid head disengaged from the baseplate during the first 3 weeks after surgery due to soft tissue interposition between the baseplate and the glenoid sphere that was unnoticed during surgery. The glenoid sphere was reinserted in revision surgery with uneventful recovery.

Two patients developed pathological fracture of acromion, two months after surgery. They made a full recovery with conservative treatment and regained full range of motion and function with no pain within a month later.

Twenty patients sustained traumatic periprosthetic fractures due to falls:

Six patients sustained traumatic fracture of the scapular spine after a fall (2 months post op, 2 years, 2.5, 6, 7 and 8 years respectively). 3 were operated with plating of the spine of the scapula, and 3 were treated conservatively. They made moderate recovery with almost no pain but limited function.

Postoperative acromial fractures have been reported in 1% to 7% of patients following all types of reverse shoulder arthroplasty.[8; 25; 34; 57]

Four patients sustained glenoid periprosthetic fracture following a fall (with well fixed glenoid components), 3 of them as early as 3 months after surgery, one patient refused further surgery, the other was treated conservatively, both with limited outcome. The third patient was revised with good outcome. The forth patient sustained late traumatic glenoid fracture combined with proximal humeral periprosthetic fracture 6.5 years following the arthroplasty and was revised.

Eight patients sustained periprosthetic fractures of the proximal humerus (metaphyseal fractures) following a fall: Six were treated conservatively and all healed with good function and two patients with displaced metadiaphyseal periprosthetic fracture had revision to a stemmed reverse prosthesis and made moderate recovery with no pain and restoration of limited function.

Two patients sustained midshaft fractures at the tip of the stemmed implant; one was revised to a longer stem Verso with strut bone allografts and the other was fixed with a plate.

All these fractures were late traumatic fractures, after the patients sustained a fall!

It is unfortunate that elderly people tend to fall and fracture bones (typically neck of femur and proximal humerus). Our patients returned to full activity following the rTSA. While performing their normal daily activities, they tripped and fell sustaining traumatic fracture of the proximal humerus or the Glenoid. Most of them were treated conservatively.

The incidence of periprosthetic fracture during or after total shoulder arthroplasty (TSA) in the literature is 1% to 3% of all TSAs. The frequency with which this injury occurs may be increasing, linked to the overall increased usage of TSA. The injury occurs in elderly patients who are at risk of falls. The majority of periprosthetic fractures occur postoperatively with low energy events after falls, during activities of daily living[6; 53; 60].

DISCUSSION

The long-term (5-11 years) clinical and radiographic results with this short metaphyseal reverse shoulder prosthesis (without a diaphyseal stem) are very encouraging. All patients had good pain relief and the vast majority of the patients were very satisfied with their shoulder (8.2/10). Good clinical outcome was observed for all the diagnoses with improvement of the Constant Score from 15.6 preop to 59.0 (Age/sex adjusted 86.8) at last follow-up.

Mazis et al. found no deterioration of the deltoid function over time with 6-11 years follow-up with the short metaphyseal without a diaphyseal stem Verso rTSA[19].

The prosthesis fixation is entirely metaphyseal with no stem in the humeral shaft. Good initial press fit fixation achieved in all patients, regardless of osteoporosis or poor bone quality, with the triple tapered finned implant in conjunction with bone graft impaction technique. The titanium porous and hydroxyapatite coatings provide further biologic fixation.

Complications related to the humeral stem with stemmed reverse prostheses accounted for 10%4 -20%62 of complications, including periprosthetic fracture, shaft perforation, disassembly, and loosening[6; 14; 57; 62]. Zumstein et al[62] reported 16 intraoperative humeral fractures and 24 intraoperative complications (67%) related to the humeral stem. Two cases in our series had an undisplaced fracture of the humeral metaphysis intraoperatively. These healed completely around the implants with conservative treatment over three weeks with no effect on the functional outcome. They did not show any lucencies or loosening at the latest follow-up.

Melis et al.[40] found radiological signs of stress shielding in substantial numbers of stemmed reverse prostheses with 5.9% of cemented and 47% in uncemented implants, as well as partial or complete resorption of the greater and lesser tuberosities (greater tuberosity resorption in 69% of cemented and 100% in uncemented implants and lesser tuberosity resorption in 45% of cemented and 76% of uncemented implants)[40]. Similar findings reported with other types of stemmed rTSA as well[52].

Neither lucencies nor resorption of bone around the humeral component suggestive of stress shielding were seen in this series. An explanation may be that as the entire fixation of the prosthesis is metaphyseal (without distal fixation) there is direct load transfer to the humeral metaphysis. This reduces the risk of stress shielding. Furthermore, use of the triple tapered finned humeral component combined with bone graft impaction technique may improve the density and resistance of the metaphyseal bone.

Scapular notching has been observed in more than 50% of cases in most series with reverse shoulder prostheses[5; 11-13; 17; 33; 40; 45; 47; 49-51; 55; 62]. This is a common radiographic finding at early follow-up[5; 11-13; 17; 33; 40; 45; 47; 49-51; 55; 62]. In Boileau et al.[4] series, notching at the inferior aspect of the glenoid was present in 74% of cases, and this extended to or beyond the inferior screw ((Nerot-Sirveaux grade 3) in 30% cases. Glenoid notching is a result of impingement of the medial aspect of the polyethylene humeral cup on the scapular neck inferiorly and posteriorly as well as further osteolysis due to the wear particles[45]. Levigne et al.[32] study confirms that scapular notching after Grammont type reverse shoulder arthroplasty is frequent, 62%, similar to some previously published reports[4; 5; 16; 32; 51; 55; 56; 58; 62]. Their study also confirms what Werner[58] previously reported, that notching occurs early after surgery, as 68% of the latest follow-up notches were already visible 1 year after the operation[58].

Melis et al.[40] reported 88% glenoid notching in series of patients with Grammont type rTSA with follow-up over 8 years. They observed increase in incidence and severity of notching over time with 62% of the notching being Nerot-Sirveaux grade 3 and 4 (49% grade 4).

Favard et al.[17] and Zumstein et al.[62] in meta-analysis, have noted a negative effect of radiographic scapular notching on the clinical outcome: if the notch is large (extending beyond the inferior screw), the Constant score was significantly lower and the risk for loosening was high in their series.

The medialisation the centre of rotation to the level of the glenoid surface and orienting the humeral cup almost horizontally have been the biomechanical solutions found by Grammont[23; 24] to avoid excessive forces on the glenoid component and improve the power of the deltoid. But, the pay off, in return, is scapular notching and polyethylene wear.

Other studies with increased lateralised centre of rotation prosthetic design have showed lower rates of glenoid notching but higher rate of mechanical glenoid failure (12% (7/60)), requiring revision[18; 26]. The use of excessive lateral centre of rotation increases the moment at the baseplate-bone interface on the glenoid and can lead to failure of the fixation. In more recent study by the same group[8], the glenoid fixation design was improved (to reduce the glenoid failures) and the glenoid baseplate placed inferiorly with a tilt to decrease notching. Cuff et al. found low rate of glenoid notching with less glenoid failures (but with 24.1% (27/112) of the patients lost to follow-up)[8].

Glenoid notching was observed in 38 cases in our series (20.5%). In 32 of these patients it was mild glenoid notching ((Nerot-Sirveaux grade 1 or 2). In these patients the glenoid notching seemed to be non progressive with sclerotic margin. Only in 6 cases a Nerot-Sirveaux grade 3 glenoid notching were observed. This low rate compares favourably with most of the published series with 44% to 96% in different series[4; 5; 11-13; 16; 45; 47; 49-51; 55].

The 3 mm lateral offset of the glenoid implant baseplate, may reduces the risk of impingement between the liner and the glenoid neck without increasing substantially moment at the baseplate-bone interface. The use of the 10°-angled dial-able polyethylene liner reduces the neck-shaft angle of the humeral component to 145°. The depth of the dialable liner socket is preserved and only the edges of the liner are removed, hence, reducing the impingement of the liner with the scapula inferiorly, as well as anteriorly and posteriorly in rotations, without increasing the risk of prosthetic instability. The use of the 10°-angled dial-able liner reduces the risk of notching as well as of osteolysis triggered by polyethylene particles[45]. According to Werner[58] and a large French multicentre study by Levigne et al.[32], notching occurs early after surgery and progress in severity with time[17; 33]. The fact that we have seen only 20.5% of glenoid notching so far in this series with this short metaphyseal reverse prosthesis, with a follow up period of 5 to 11 years is very encouraging.

The rate of glenoid component loosening reported in the literature for rTSA range between 2% to 5%[11; 12; 15; 28; 47; 51; 55; 62]. No radiolucent lines were seen around the glenoid component in our series so far, with follow-up of 5 to 11 years. Hopkins et al.[27] assessed the glenoid components of six different reverse shoulder prostheses and compared the primary stability through the minimisation of interface micromotions. The glenoid baseplate of this short metaphyseal rTSA design was the most stable with peak micromotions of less than 48 microns. When the relative displacement of the bone-implant interface (termed 'micromotion') is below a threshold of 150µm, it is assumed that the implant will not induce the generation of unwanted fibrous tissues[46], and micromotions below 50µm are considered low enough to allow bone ingrowth.

Some authors raised concerns that use of the Grammont type reverse arthroplasty may lead to deficient or absent external rotation and internal rotation[4; 20; 30; 39; 61]. This may affect the functional ability of patients to perform their simple daily activities[20].

We have found significant improvement in the rotational movements in our series compared to published series with other reverse prostheses[4; 20; 30; 39; 61]. Karlse et al.[30] described the hinging movement of the rTSA humerus around the centre of rotation compared with the anatomic shoulder that spins around the centre of rotation. Karlse et al.[30] showed that there are limitations of rotation movements with rTSA due to impingement of the hinging humeral cup component around the glenoid head. In the adducted position the contact between the inferior edge of the humeral component and the body of the scapula limits the range of adduction. Similar, with internal and external rotation - limiting the range of rotational motion[30]. Removing the edges of the polyethylene liner increases the range of the humeral component rotational movement before impingement of the liner on the scapula occurs.

Indeed, asymmetric polyethylene wear has been observed on most retrieved humeral reverse prostheses liners [10; 42; 43; 45].

The use of the oblique dial-able liners of this implant (Figure 1) combined with 3 mm lateral offset of the glenoid sphere and insertion of the humeral shell in 30° of retroversion may explain the improved rotation. Furthermore, the humeral liners can be dialled in a way that the correct version and offset of the liner can be determined and changed, adapted to each patient, even after the definitive metal implants have been implanted. Beside, reduction of the impingement on the glenoid, these may position the vectors of action of the most anterior and the most posterior fibres of the deltoid muscle in a more horizontal position and recruit them as internal and external rotators respectively[4].

Reverse TSA are usually implanted in elderly patients, which have tendency to suffer from trips and falls. They therefore, have an increased risk to suffer late traumatic periprosthetic fractures[1; 6; 62].

If a stemmed prosthesis is used, the periprosthetic humeral fracture tends to happen at midshaft of the humerus (at the metal-bone interface stress riser)[1; 6; 62]. Andersen et al.1 concluded that periprosthetic fracture around a humeral stem implant is a difficult clinical problem involving complex decision-making, difficult surgery with frequent complications and high reoperation rate.

Zumstein et al.[62] observed negative impact on the clinical outcome in cases with postoperative periprosthetic humeral shaft fractures after stemmed rTSA that had to be revised with longer stems.

Using short metaphyseal without a diaphyseal stem prosthesis reduces the risk of diaphyseal periprosthetic fracture. If fracture is to happen, it will involve the metaphysis rather than the humeral shaft. Metaphyseal fractures may heal better than diaphyseal ones with conservative treatment as shown in this study.

Indeed, the incidence of intraoperative humeral fracture for primary reverse arthroplasty and in revision of a resurfacing device to a reverse is low. However, the risk is clearly higher when using stemmed implants requiring preparation and reaming the humeral shaft for the prosthesis, compared with no need at all to touch the shaft in stemless/metaphyseal prosthesis!

Furthermore, intraoperative humeral fractures are more of a problem in revision surgery. We are seeing 'exponential' increase in revisions of both anatomic and reverse TSA in recent years![9].

By using prosthesis without a stem we reduce the risk of intraoperative humeral fracture if revision will be necessary.

There are limitations to the use of stemless/short metaphyseal without a diaphyseal stem reverse implants, as they are not suitable for treatment of cases with acute fractures, fracture nonunions or revision of stemmed prostheses. For these cases a stemmed implant should be used.

CONCLUSIONS

The bone preserving short metaphyseal rTSA design without a stem shows encouraging long-term results with excellent pain relief and shoulder function, restoration of good active range of motion and high patients' satisfaction scores. These good clinical outcomes are maintained over time for over 11 years. Radiographically, no implant loosening, subsidence or stress shielding observed. The design of this implant seems to result in low incidence of glenoid notching (with low grade of notching) and improved rotational movements compared to the Grammont type prostheses.

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39/ STANDARD VERSUS BONY INCREASED-OFFSET REVERSE SHOULDER ARTHROPLASTY. A RETROSPECTIVE COMPARATIVE COHORT STUDY RUNNING TITLE: BIO VS. STANDARD RSA

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INTRODUCTION

Several problems after reverse shoulder arthroplasty (RSA), including scapular notching, lack of improvement in rotation, instability, and loss of shoulder contour, have been attributed to the medialized glenoid design.10; 24 To address these problems, some authors have proposed increased glenoid lateralization via either bone grafting (bony increased offset (BIO-RSA)) or prosthetic lateralization of the sphere or baseplate.3; 12
Reported advantages of increased lateralization include decreased scapular notching and improved external and internal rotation.3 However, lateralization may have negative consequences such as decreased mechanical advantage of the deltoid and the need for graft healing in the case of a BIO-RSA. To date, only a few comparative studies with small sample sizes have compared a BIO-RSA to a traditional RSA without bone graft (tRSA).1; 11 The aim of this study was to compare the clinical and radiological results of tRSA to BIO-RSA. The hypothesis was that patients with BIO-RSA would have decreased scapular notching and improved range of motion (ROM) and functional outcome.

MATERIALS AND METHODS

Study design, study population, and data collection
A retrospective review was performed of RSAs performed at a single institution between November 2009 and October 2013 in order to compare tRSA to BIO-RSA. Data was collected in a prospective fashion and reviewed retrospectively following institutional review board approval (CERC-VS-2016-07-1 BLIND FOR REVIEW PURPOSES). Inclusion criteria were a primary RSA with a minimum follow-up of 2 years. Patients with fracture sequelae, history of infection, or presence of neurological problems such as Parkinson's disease, or glenoid bone loss were excluded. Bone loss was excluded because inclusion would have prevented analyzing the effect of lateralization. Effectively, the goal of the study was to compare standardized surgeries with either no or 10 mm of glenoid lateralization. The flow chart in Figure 1 resumes the patient selection.

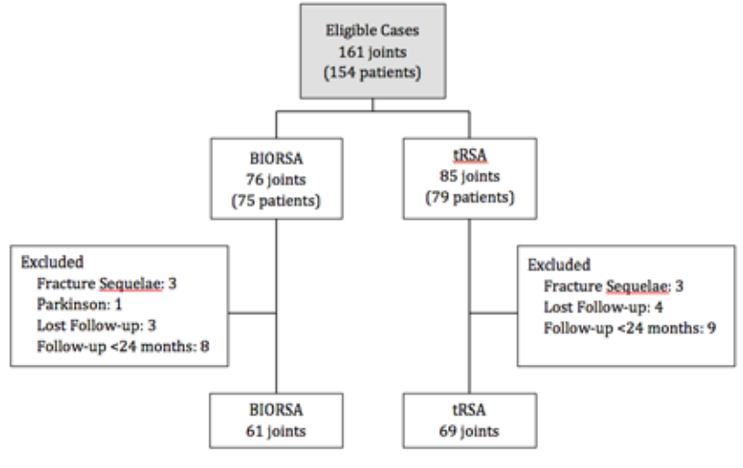

Figure 1
Flow chart of the study

Surgical technique

All surgeries were performed by an experienced13; 22 shoulder surgeon who had performed over 250 RSAs prior to the study period (PC BLIND FOR REVIEW PURPOSES). During the study period there was a change in technique with regard to treatment of the glenoid. From November 2009 to June 2011 all patients were treated with a tRSA. The BIO-RSA technique was then adopted and from July 2011 to October 2013, this was the standard approach for RSA. The Aequalis shoulder prosthesis system (Aequalis Reversed; Wright Medical, Montbonnot, France) was used for both the tRSA and the BIO-RSA. A standard deltopectoral approach was used in all cases. The only difference between the two procedures was the BIO-RSA addition of harvesting of a 10 mm humeral head autograft and application to a 25 mm long post baseplate (as opposed to a 15 mm post in the tRSA) prior to placement in the glenoid.3 A 29 mm circular baseplate (Aequalis Reversed; Wright Medical, Montbonnot, France) was implanted at the inferior edge of the glenoid surface and a centered 36 mm glenosphere with a center of rotation at the glenoid surface was placed over the baseplate. All humeral stems had a neck-shaft angle of 155 degrees and were cemented following insertion of a cement restrictor plug. Postoperatively, the arm was placed in a sling for 4 weeks. Passive elevation and external rotation were allowed immediately following surgery15. After 4 weeks, the sling was discontinued and active ROM was initiated. 18. Activities of daily living were progressed but strengthening was no specifically recommended. 4

Clinical evaluation

Baseline characteristics recorded included age, gender, and limb dominance. All patients in both groups were examined preoperatively and 2 years postoperative. Shoulder ROM and Constant score were evaluated by an examiner independent to the operating surgeon (Soleen Gain BLINDED FOR REVIEW PURPONSES).6 ROM was assessed on a video recorded physical examination. Active forward flexion in the plane of the scapula and external rotation with the arm at the side were evaluated using a digital goniometer (Dartfish express; Dartfish © Alpharetta, GA, USA). Internal rotation was estimated to the highest vertebral level reached with the patient's extended thumb.

Radiographic evaluation

Standardized anteroposterior in neutral, external and internal rotation, and axillary lateral radiographs were obtained under fluoroscopic control preoperatively and postoperatively. Postoperative radiographs were assessed for bone graft incorporation defined by the absence of lucent lines observed between the humeral bone graft and native glenoid, inferior notching at native glenoid, radiolucent lines (around the peg, screws and humeral stem), and shift in position of the components. The severity of the inferior notching was graded according to Sirveaux classification.20 Analysis of the superior aspect of the bone graft is difficult because the coracoid process often overlaps the superior aspect of the joint line. Therefore, we focused on the inferior aspect of the graft, below the level of the central peg. For the BIO-RSA cohort, inferior graft incorporation was also graded according to the system of Boileau.3

Statistics

A sample size calculation indicated that 36 patients were needed in each group in order to detect a minimal clinically important difference of 10 points for the Constant score. Statistical analysis was performed with SPSS 18.0 (SPSS Inc, Chicago, Illinois). Demographic data, functional outcome, and ROM were compared with an independent samples t test. Radiographic characteristics were analyzed with a chi-squared test. Significance was assumed at $p<0.05$.

RESULTS

A total of 161 RSAs were performed in the study period. Twenty-four were excluded based on the study criteria and 7 were lost to follow-up leaving 61 (85% follow-up) BIO-RSAs and 69 (84% follow-up) tRSAs (Figure 1). The demographic data was similar between the two groups (Table 1). One patient in the tRSA group experienced an instability episode which failed closed reduction and required exchange to a larger glenosphere and polyethylene (42 mm).

Compared with baseline values, overall there was a significant increase in ROM and improvement in Constant score at 2 year follow-up (Table 2). At 2 years follow-up, anterior forward flexion was significantly higher following a BIO-RSA compared to a tRSA group (145 ± 21 degrees vs. 138 ± 20 degrees respectively, p=0.017). There was no significant difference in active external rotation or internal rotation between the two groups. Patients in the BIO-RSA group had significantly higher Constant scores (BIO-RSA 69.0 ± 9.4 vs. tRSA 61.4 ± 12.7; $p<0.01$) (Table 3).
Evaluation with plain radiographs at 2 year follow-up demonstrated no significant difference between the two groups including notching (Table 4).

DISCUSSION

The hypothesis of this study was not confirmed. The patients in the BIO-RSA group did not demonstrated clinically significant improvement in ROM compared to a traditional RSA without bone graft. Moreover, there was no difference in radiographic findings between the BIO-RSA and tRSA groups. These findings have several implications important to RSA.

It is well established that AFF and Constant scores are significantly improved in most patients after RSA7; 17; 23 but few studies have compared BIO-RSA to tRSA. Greiner et al. performed a randomized controlled trial of 17 tRSAs and 17 BIO-RSAs and reported no difference in Constant scores at 1 year postoperative.11 While they reported external rotation, they did not report anterior forward flexion. In a retrospective study, Athwal et al. did not observe substantial differences between tRSA and BIO-RSA with respect to ROM, strength, or outcome scores.1
In the current study, we observed slightly higher anterior forward flexion and Constant scores with the BIO-RSA technique at 2 years follow-up. Our ability to detect a statistically significant difference in the Constant score may be related to our larger cohort size. However, the observed differences are not likely clinically important as the differences are small in magnitude.
In contrast to anterior forward flexion, external and internal rotation typically remain compromised or even decrease after a tRSA.19; 23 Several authors have reported improvement in rotation with a lateralized glenoid.3; 9; 21; 23 However, comparative studies have failed to bear out a difference in rotation. In the aforementioned study by Greiner et al., external rotation at the side was 18 degrees in the tRSA group and 28 degrees in the BIO-RSA group but this difference did not reach statistical significance ($p = 0.302$).11 Athwal et al. reported that external rotation at the side was 23 degrees in both groups ($P=0.999$).1 Likewise, in the current study there was no difference in external rotation at side between the tRSA and BIO-RSA groups. Several factors may explain these findings. First, a BIO-RSA may not decrease friction type impingements14 since there is still medial bone (graft) for the humeral component to abut upon. It is possible that prosthetic lateralization via either baseplate offset or glenosphere offset would lead to different results. Second, the BIO-RSA lateralizes the center of rotation which may decrease recruitment of the deltoid for rotation (Figure 2). The latter factor is important, as deltoid compensation may allow maintenance of active external rotation even in the absence of the teres minor.5 It is possible that the impact of lateralization varies based on the remaining rotator cuff. For instance, glenoid lateralization may be advantageous if a portion of the subscapularis and the infraspinatus are intact, because lateralization leads to restoration of Blix curve (Figure 2).2 However, in the case of a massive anterior or posterior rotator cuff tear, medialization of the center of rotation may be more advantageous for the deltoid (Figure 2). In addition, rotation may be affected by humeral inclination. The humeral implants in our study and the study by Greiner et al. had a humeral inclination of 155 degrees. This design leads to a distalized center of rotation which may negatively impact the mechanical ability of the remaining rotator cuff to perform rotation. Results may be different with a more vertical or anatomic humeral inclination.

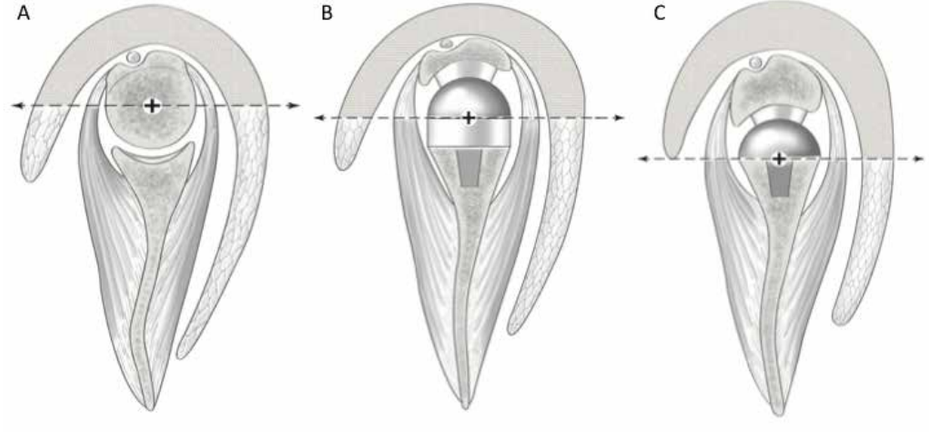

Figure 2
A) Native shoulder. The center of rotation is in the humeral head and the level of arm of deltoid does not allow deltoid recruitment.
B) BIO-RSA (Lateral Glenoid/Medial Humerus Design). Like in native shoulders, the bony lateralization of the center of rotation decreases recruitment of the deltoid for rotation.
C) Grammont RSA with humeral lateralization (Medial Glenoid/ Lateral Humerus Design). Medialization of the center of rotation and humeral lateralization allows important deltoid recruitment.

The reported incidence of notching in the literature with RSA is up to 88%.16 Increased glenoid lateralization has been reported to decrease scapular notching.3 Athwal et al. found a significantly higher rate of notching in tRSA compared to BIO-RSA (75% vs 40%, P=.022). In contrast, in our study there was no difference in notching with the two techniques. Scapular or graft notching is the result of combined movements of adduction, extension and rotation.14 As noted previously, we believe this reflects the fact that the humeral inclination in both groups was consistent and the humerus continued to abut upon bone (graft or native scapula). The similar rate of notching observed in the current study is also supported by the absence of improvement in adduction, extension and external rotation elbow at the side between a tRSA and a BIO-RSA (-15 vs -14 degrees, -7 vs -8 degrees, and -16 vs -18 degrees, respectively) observed in a virtual RSA model.14

Strengths and limitations

The major strengths of this study are the cohort size and close follow-up. The patient selection was strict with exclusion of preoperative glenoid erosion. However, this study has several limitations. First, although one surgeon and an independent examiner were involved in the evaluation, they were not blinded to the device type. Moreover, clinical outcomes were limited to 2 year follow-up. We cannot, therefore, conclude whether differences, such as graft osteolysis or loosening in the groups, occur in the long-term. Only plain radiographs were available for analysis. Nevertheless, it has previously been demonstrated that bone graft resorption may be underestimated with computed tomography scans due to metallic artifacts of the baseplate and glenosphere.8 Finally, the results are limited to the humeral inclination of 155 degrees and lateralization method in the current study. Further study is needed to evaluate prosthetic lateralization with and without a different humeral inclination.

CONCLUSION

At 2 year follow-up, BIO-RSA does not lead to clinically significant improvement in ROM or Constant scores and does not prevent scapular notching compared to a tRSA. Results emerging from a compromise between glenoid and humeral lateralization need to be evaluated in future studies.

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40/ RSA IN IRCT AND COST EFFECTIVENESS

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INTRODUCTION

Rotator cuff tears (RCT) are a common condition especially in the aged population and its evolution significantly influence the quality of life for patients and are one of the most common reasons for orthopedic clinic visits. Approximately 10% to 40% of all RCTs are massive (greater than 5 cm in size or complete detachment of 2 or more tendons) [1-3]. Each year in the U.S. approximately 4.5 million patient visits are due to shoulder pain, and the majority of them are associated with RC pathologies. A substantial proportion of these tears are determined to be irreparable on evaluation [4]. Thus, massive irreparable RCTs present a challenging clinical problem for both patients and orthopedic surgeons.

Many Options for treatment have been proposed, including physical therapy and arthroscopic debridement with biceps tenotomy that have demonstrated to reduce pain and improve quality of life [5,6]. However, surgical treatment options, such as hemiarthroplasty (HA) and reverse total shoulder arthroplasty (rTSA), may result in better functionality achievements [7,8] especially when arthritis is progressing the gleno-humeral joint. Recent studies have shown that RTSA has the potential to achieve better functional outcomes compared with other treatment strategies [9]. However, RTSA has been associated with higher complication and reoperation rates as well as greater costs [8,10].

More recently other technologies have been introduced to treat this painful condition such as the InSpace™ system, commonly known as balloon arthroplasty or subacromial spacer [11] with the aim to warrant a a minimally invasive surgical technique using a biodegradable subacromonial balloon spacer implanted between the humeral head and acromion that enables frictionless gliding to restore shoulder biomechanics. This device device can be easily inserted under fluoroscopic guidance with patients under local anesthesia on an outpatient basis [12] or with a simple and fast arthroscopic procedure.

The data regarding the cost effectiveness of treatment options for shoulder arthropathy in massive irreparable RCTs is scarce. Recent study by Longo et.al confirmed that the socioeconomic burden of RC surgery is growing and heavily affecting the working population in Italy [13].

Rationale of Cost Effectiveness

Cost effectiveness of a surgical procedure can be a tricky process.

Most of the surgeons believe that the "cost" is basically related to the economic cost of the implant(s) and the associated cost of th surgery (OR time, anesteshists etc).

However the Social economics are more and more focusing on these aspects due to the increasingly significance of the impact that medical care has on local administrations.

The economic evaluation uses an expected value decision analytic model to compare estimated outcomes associated with the management of Arthropathy in IRCT in terms of cost per quality-adjusted life-years (QALYs) gained.

Furthermore the overall cost should include the risk of complication(s) and possible revision(s) that are part of the entire treatment itinerary of the patient.

For these reasons a study model should be built to evaluate the entire course and outocome of the indexed procedure and analyzed with dedicated software.

As an example of this approach the Author reports a recently published study that compares the cost effectiveness of four different approaches to IRCT (RSA, Arthroscopic Debridement, Rehabilitation, Subacromial Spacer). For each IRCT treatment strategy, the course of treatment and outcomes are represented (Figure 1).

In this study costs represent direct medical costs to the healthcare system and were sourced from published literature and based on US Medicare cost of surgical costs, including the cost of the procedure, implant costs, and costs of hospital care. All costs were normalized to 2017 US dollars using a cumulative inflation rate based on the Consumer Price Index (CPI) for health care services (use Sundar source). They were then translated into Italian healthcare Euros using the purchasing power parity (PPP) conversion factor, which is the number of units of the country of the country's currency required to buy the same amounts of goods and services in the domestic market as the US dollar would buy in the United States, currently 0.75 for Italy. PPPs show the ratio of prices in national currencies of the same good or service in different countries. They were then translated into Italian health care system Euros using a purchasing power parity (PPP) of 0.75. The cost of InSpace and assumed to be less than the cost of rTSA and similar in cost to arthroscopic repair. This input was validated by a review of Italian hospital charges.

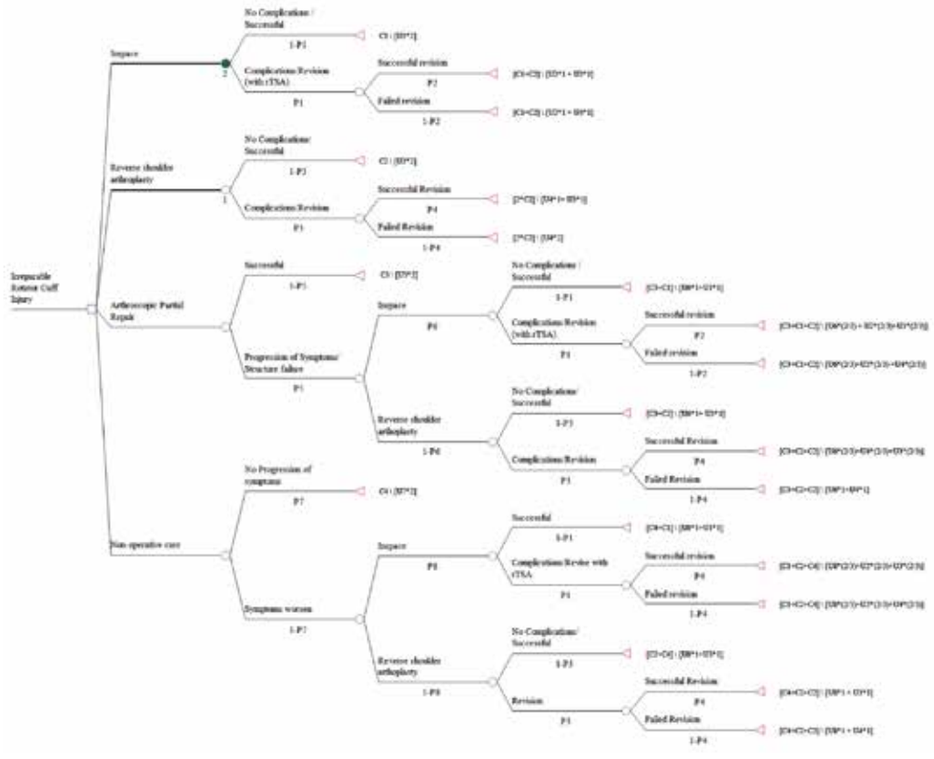

Figure 1
Model Structure: Treatment alternatives for Arthritis in Irreparable Rotator Cuff Tears (IRCT)

A probabilistic subset of those patients will have success with a treatment or course of action, while the remaining will require revision or another treatment, which also has a probability of success or failure, based on the prior treatment and outcome. As shown in Figure 1, if a patient begins with non-operative care but symptoms worsen, they will proceed to either rTSA or Subacromial Spacer . For patients undergoing partial repair, they may either have a successful procedure or require a revision. As with patients receiving non-operative care, if they require revision, they will either undergo rTSA or receive Subacromial Spacer. For patients initially undergoing rTSA, their procedure will either be successful or will require a revision procedure. If they require a revision, the revision will either be successful or fail. If the revision fails, they will remain in that health state. If a patient initially utilizes Subacromial Spacer, they will either have no complications or require a revision (rTSA) which will either be successful or fail. If the revision fails, the patient will remain in that health state. Thus, a weighted average of the possible returns for each alternative (costs and QALYs), with probabilities used as weights, is calculated.

In the model we operated under several assumptions regarding the patient treatments and costs: (1) all patients entering the model are diagnosed with IRCT; (2) prior to entering the respective treatment arms, patients underwent equivalent prior non-operative care of 6 weeks with equivalent costs; (3) costs included direct medical care costs; and (4) patients who experience complications following surgical care require revision surgery. Additionally, model parameters, displayed with their corresponding data sources in Table 1, consist of costs, health utilities, and transition probabilities.

As reduced quality of life (QoL) is associated with both disease treatment and disease health outcomes (Whitehead, 2010), we incorporated QoL for each health outcome of interest using estimates of utilities reported in the peer-reviewed literature. In this analysis, health utilities measure quality of life on a 0-1 scale anchored by death (0) and perfect health (1); and are associated with each IRCT treatment outcome. The primary patient outcome of interest for this analysis is the total quality-adjusted life-years (QALYs) experienced by the patient over the course of the 24 period. The timeframe was

chosen based on the length of follow-up time in recently published studies. We assume that treatment decisions (i.e. revision) are made within one year, allowing a year of follow-up time. Thus, the impact of each treatment strategy was measured in quality-adjusted life-years (QALYs) over the course of the treatment period. Utilities are used to calculate quality-adjusted life years (QALYs) experienced by a patient by decrementing the amount of time that has passed by the health utility experienced during that time period. For example, a patient experiencing perfect health (i.e., health utility = 1) for a period of two years will experience 2 QALYs during that two-year period. A patient experiencing a health utility of 0.5 will experience 2*0.5 = 1 QALY during that two-year period.

Movement through the decision tree, shown in Figure 1, is governed by: (1) the success or failure rates of the various IRCT management strategies; (2) the likelihood of revision procedures; and (3) the success or failure rates of the revision procedures. These model transition probabilities were derived from the literature and their values and data sources are also displayed in Table 1+2. As hypothetical patients traverse the model, applicable costs and outcomes (health utilities) associated with the treatment alternatives for IRCTs accrue. Using the accrued cost and accrued utilities as the effectiveness parameter for each potential path through the model, the model evaluates the expected cost and expected QALYs based on the transition probabilities for each treatment strategy.

Costs (€)				
Variable	**Description**	**Base Case**	**Range from lit review**	**References**
C1	Cost InSpace™	15000	12000-18000	Assumption based on Makhni and Kang 2016
C2	Cost of Total Reverse Shoulder Arthroplasty	28210	17619 - 55359	Renfree 2013, Virani 2013, Makhni 2016, Kang 2016
C3	Cost of Partial Arthroscopic Repair	11739	8306 – 17413	Makhni 2016, Vitale 2007, Genuario 2012, Mather 2013, Bisson, 2015, Kang 2016
C4	Cost Non-operative Care	9068	7254 - 10882	Makhni 2016
Utilities				
U1	Successful InSpace™	0.700	0.560 – 0.840	Assumptions
U2	Complication InSpace™	0.660	0.520 - 0.792	Assumptions
U3	Successful rTSA	0.660	0.600 – 0.900	Makhni 2016, Kang 2016
U4	Complication rTSA	0.411	0.411 – 0.700	Makhni 2016, Kang 2016
U5	Healed Partial Repair	0.662	0.510 – 0.770	Makhni 2016, Kang 2016
U6	Re-torn Partial Repair	0.656	0.470 – 0.710	Makhni 2016, Kang 2016
U7	No progression of symptoms non-operative care	0.662	0.56 – 0.84	Makhni 2016, Kang 2016
U8	Symptoms worsen (retear) Non-operative care	0.660	0.56 – 0.84	Makhni 2016, Kang 2016
P1	Probability of Revision (Inspace™)	0.125	0.40 - 0.125	Gervasi 2016, Study Powerpoint
P2	Probability of successful revision (Inspace™)	0.50	0.40 – 0.60	Assumption, Makhni 2016
P3	Probability of Revision (rTSA)	0.10	0.10 – 0.69	Anley 2014, Russo 2015, Kang 2016,
P4	Probability of successful revision (rTSA)	0.50	0.10 – 0.84	Anley 2014, Russo, Makhni 2016 2015, Kang 2016, Holschen 2017
P5	Probability of Structure failure with arthroscopic partial repair	0.52	0.10 – 0.52	Berth 2010, Kang 2015
P6	Probability of Inspace™ if arthroscopic partial repair structure fails	0.50	0.40 – 0.60	Assumption
P7	Probability of Success with Non-operative care	0.68	0.68 – 0.82	Mather 2013, Kang 2016
P8	Probability of Inspace™ if symptoms persist with Non-operative care	0.50	0.40 – 0.60	Assumption, Makhni 2016

Table 1
Model Parameters with Base-Case and Sensitivity Analysis Range

Cost-effectiveness Analysis

All analyses were conducted by following the recommendations from the ISPOR Panel on Cost Effectiveness in Health and Medicine. Comparisons of strategies were made using the incremental cost-effectiveness ratio (ICER), which is the ratio between the difference in costs and QALYs of each strategy compared to the previous strategy, when strategies are ordered by cost, e.g. incremental dollars per QALY. A willingness to pay (WTP) threshold for the additional cost incurred for each change in QALYs is established. Typically, strategies with an ICER of less than 50,000 US dollars (45,483 Euros) are considered cost-effective. A strategy is dominated when another is both less costly and more effective and is dominant when it costs less and is more effective. A strategy with a negative ICER is dominated, reflecting the additional cost per loss in QALYs. Incremental analysis is critical for decisions regarding the allocation of scarce resources. The "base-case" analysis is the scenario which involves evaluating the model with each parameter at its estimated value. One- and two-way sensitivity analyses were performed to explore the impact of varying key parameter values from the base case on the model results.

RESULTS

Base-Case Analysis

The expected costs, QALYs, and ICERs associated with each treatment alternative are presented in Table 2.

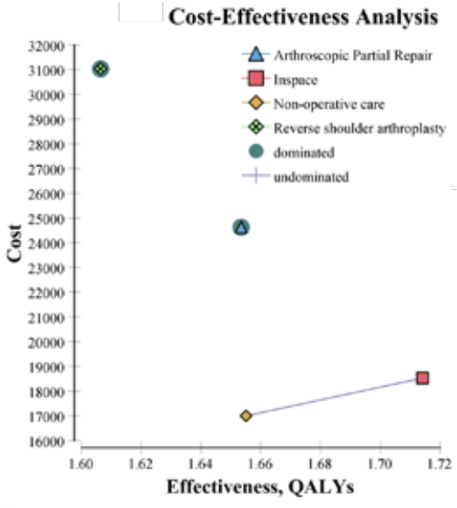

Figure 2
Graph of Base-case Cost-effectiveness Analysis

Subacromial spacer dominates both arthroscopic partial repair and reverse shoulder arthroplasty since it costs less than both options and increases effectiveness by 0.06 and 0.10 QALYs, respectively. While non-operative care is the least costly management strategy, the Spacer results in a gain of .05 QALYs for the additional cost of 522 , resulting in an ICER of 10,440 /QALY gain, which is below the standard willingness to pay ratio of $50,000 US dollars. Typically, strategies with an ICER of less than 50,000 US dollars (45,483 Euros) are considered cost-effective.

Arthroscopic partial repair and rTSA are both dominated since both are more costly and less effective than and non-operative care. Arthroscopic partial repair is more effective but slightly more costly than non-operative care. When a WTP of $50,000 (45,483 Euros) is used, InSpace™ is the preferred strategy. (rTSA, reverse total shoulder arthroplasty; WTP, willingness-to-pay.)

Management Strategy	Total Expected Per Patient Cost €	Total Expected Per Patient QALYs	Incremental Cost €	Incremental Effectiveness QALYs	Incremental C/E (ICER)
Non-operative care	16,805	1.33			
Subacromial Spacer	17,327	1.38	522	0.050	10,440
Arthroscopic Partial Rotator Cuff Repair	24,312	1.32	6,985	-0.060	-116,417
Reverse shoulder arthroplasty	31,031	1.28	6,719	-0.040	-167,975

Table 2
Base-Case Cost-Effectiveness Analysis

Utility Sensitivity Analysis of Surgical Treatments

Figure 3 shows the results of the two-way sensitivity analysis between the utility of successful Subacromial Spacer and successful rTSA in a comparison of the three surgical treatments. Across the grid, the colors represent the preferred strategy based on the net monetary benefit (NMB) using a WTP strategy of $50,000 US dollars (45,483 Euros). InSpace™ was preferred with a utility greater than 0.55 and a difference no greater than 0.20 between it and rTSA, while rTSA was only preferred if the utility difference was larger than 0.20. Partial arthroscopic repair was only preferred when the utility of InSpace™ was below 0.55 and utility of rTSA below 0.75.

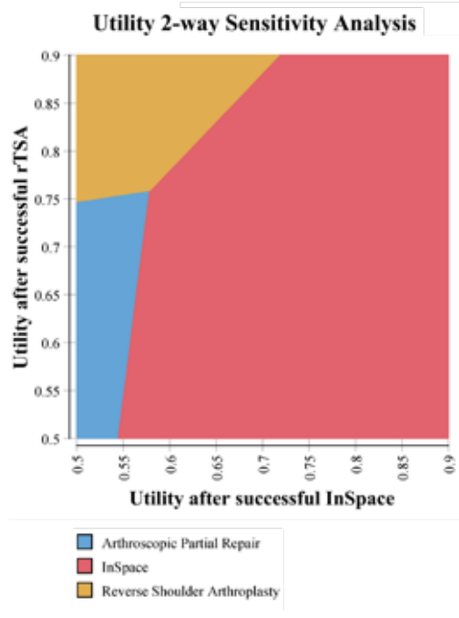

Figure 3
Two-Way Sensitivity Analysis plot for utility after successful Subacromial Spacer versus utilty after successful rTSA. The colors represent the preferred strategy for the combination of the 2 parameters based on NMB when a WTP of $50,000 (45,483 Euros) is used

DISCUSSION

The principal results of this cost-effectiveness study clearly indicate the cost-effectiveness can be very much variable when all the parameters are considered including complications and their treatment

There is an unmet need to determine the value of operative treatment for Arthropathy in IRCTs, with value determined by reductions in costs to society from rotator cuff repair. The most clinically and cost-effective strategies available to treat Arthropathy in IRCTs in the countries we assessed were those that enhanced reduced sequelae, improved mobility, and decreased the need for revisions, through either a reduced number of visits or improved follow-up. It should be noted that while this analysis uses Italian perspective costs, the model could be analyzed utilizing cost data from other countries to develop additional cost-effectiveness analyses.

Although our cost-effectiveness analysis is adaptable for various cost perspectives and patient populations and includes current IRCT treatment options and standards of care with published literature justification, this analysis is not without limitations.

In this analysis, a 24-month time frame is employed. However this was chosen to represent the common course of treatment and allow for model flexibility of multiple age groups. Although, this analysis is not specifically designed for a particular age group, the model has the flexibility to vary key parameters, in particular success and failure rate utilities.

By necessity, the cost analysis reported in this study reflects the medical economics in Italy, which may be different in other countries. However, the study does provide incremental changes in a large variety of the patient's metrics, which should provide surgeons in other countries with the tools to adjust this analysis according to their local situation. Recent study by Longo et al. [13] reported that rate of RC repair in Italian hospitals is increased between 2001 and 2014, confirming that the socioeconomic burden of RC surgery is mounting. Approximately 65% of RC repairs were performed annually in patients younger than 65 years, thus heavily affecting the working population. According to the prediction model, hospital costs sustained by the national health care system for RC related pathologies procedures are expected to be over 1 billion euros by 2025 [13].

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41/ PRE-OP PLANNING AND NAVIGATION IN TOTAL SHOULDER ARTHROPLASTY

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INTRODUCTION

Clinical outcomes and implants durability depend on the biomechanical alignment, soft tissues tensioning, and anatomical reconstruction of a total shoulder arthroplasty.[1-5]
During the procedure, the visual landmarks are not always adequate for precisely establish the mechanical axis of the joint. Pre-operative planning and navigation tools are very useful to help the surgeon to meet theses goals. [6,9]
We report here our preliminary experience with the Exactech Shoulder GPS® system that we are using for all our shoulder arthroplasties since September 2016.

PLANNING

Based on a CT-scan, Blue Ortho technicians provide the surgeon a 3D model of the scapula with the Friedman axis position that allows determining the best implant size and position. (Fig.1)

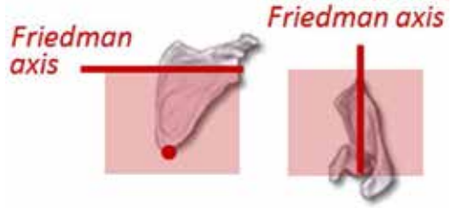

Figure 1
The inclination is calculated with respect to the frontal plane of the scapula. This plane is defined by the Friedman axis and the lowest point of the scapula. The version is calculated with respect to a plane passing through the Friedman axis, orthogonal to the frontal plane of the scapula

It is particularly very useful in small glenoids to avoid the risk of perforation or on important deformations to adjust asymmetric reaming or augmented implants.
It helps a lot to preserve bone stock. (Fig.2)

Once the planning is completed, it is saved on a jump drive stick that will be uploaded on the navigation workstation in the operating room.

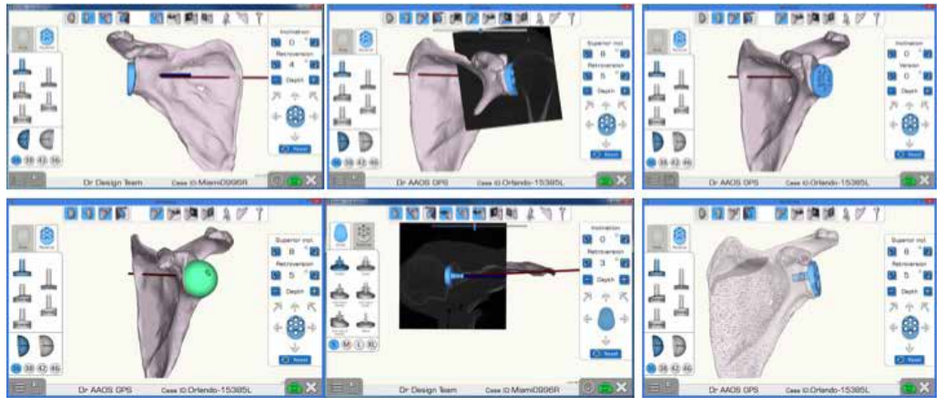

Figure 2
The preoperative planning software allows the selection of the most suitable implant and adjustment of its position. The visualization on CT slices limits the risk of perforation

NAVIGATION

The standard procedure in not modified since the trackers are fixed on conventional instrumentation. (Fig.3)

Figure 3
Surgical instruments are successively mounted on a single shaft connected to instrumental sensor (T sensor) communicating with the GPS station

The touchscreen of the navigation system is accessible in the surgical area with a special draping. (Fig 4)

Figure 4
The touch screen of the GPS station is accessible in the operating field protected by a transparent sterile cover and fixed on a support attached to the side rail of the table

A tracker is fixed on the coracoid process that doesn't require any additional approach. (Fig.5)

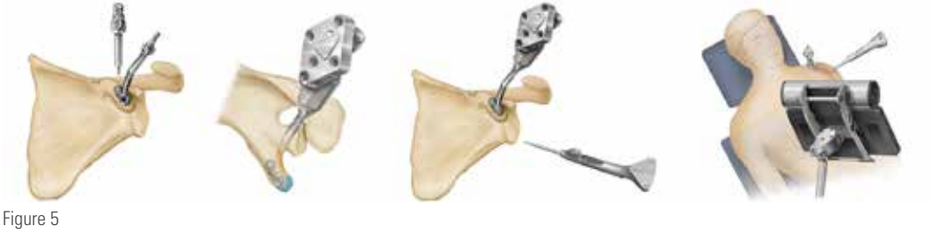

Figure 5
The tracker is attached to the coracoid process, it communicates with the GPS system and the sensor that will be used to perform the acquisition of anatomical landmarks.

The figures below illustrate the navigation procedure that starts with the acquisitions. (Fig. 6-10)

Figure 6
After the acquisitions, the system displays the result of registration between the anatomy of the patient and the 3D model from the scanner images. The colors indicate the accuracy obtained in areas where the points were earned.

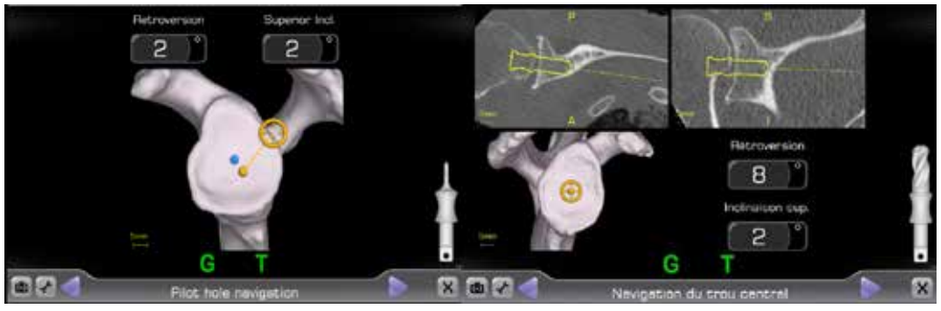

Figure 7
For the drilling steps, the tip of the instrument is displayed in yellow on the screen and should be superimposed on a blue dot corresponding to the planning. Then align the axis of the instrument with a target that will center on the yellow dot

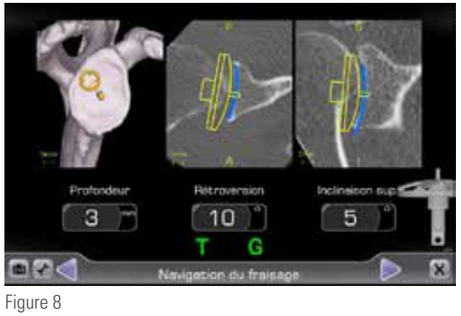

Figure 8
It is possible to visually check the reaming orientation and depth.

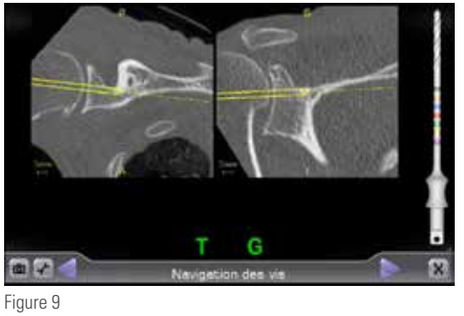

Figure 9
The system allows visualizing the orientation and length of the screw on CT slices

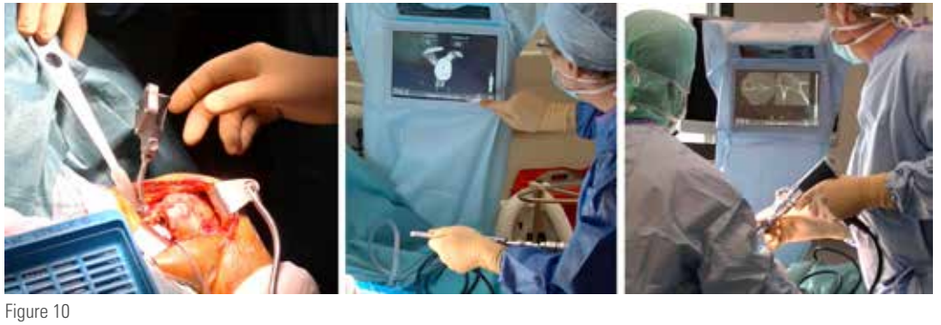

Figure 10
Using the GPS system in the operating room

Each step of the surgery is displayed successively on the navigation screen but the surgeon is still free to skip a step or to backtrack to the previous step. The 3D reconstruction and CT-slice views give a constant feedback on the position of the prosthesis in relation to the Friedman axis in terms of inclination and version.

CONCLUSION

After one year and more than 150 procedures GPS navigation system appears to improve the quality of glenoid implantation based on X-rays that fit well with the planning. a clinical study is in progress to compare prop planning with post-op CT-scan. Preliminary results are validating the use of the system. During these procedures we did not experiment any significant technical difficulty with, particularly no tracker fixation loosening and no navigation failure.
The learning curve has been estimated to seven cases with, after the learning curve, an additional time of 3 minutes for aTSA and 6 minutes reduction of time for rTSA.
The next development of the GPS navigation system will

be the use of navigation for the humeral implant.
The development of this navigation system will be the possibility of automated segmentation from CT slices and navigation of the humeral implant.

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42/ 3D PRE-OPERATIVE PLANNING AND PSI FOR CORRECTION OF HIGHLY DEFORMED GLENOIDS IN PRIMARY OA

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INTRODUCTION

Correction of glenoid deformity in primary osteoarthritis is key to the successful restoration of the joint line and centering of the humeral head in anatomical total shoulder arthroplasty (TSA). Failure to address pathological version and/or inclination of the glenoid surface may lead to poor function and early glenoid component loosening[6,7]. Traditionally, the most common corrective techniques have included asymmetric reaming of the anterior glenoid and posterior glenoid bone grafting[9,11]. More recently, augmented glenoid components have been introduced. Reverse shoulder arthroplasty (RSA) is also now increasingly used for older patients with more advanced posterior glenoid bone loss[10]. Management of this pathology in younger or more active patients remains an unsolved problem.
The use of 3D planning and patient specific instrumentation (PSI) has been shown to improve accuracy in glenoid component positioning in both TSA and RSA[2-4,14]. More specifically, its greatest benefits were shown when there is more than 16° of glenoid retroversion[3]. This study aims to evaluate if 3D planning and PSI results in accurate correction of highly deformed glenoids in the younger, active patients with primary osteoarthritis enabling solid implantation of a standard anatomical glenoid component and centering of the humeral head.

MATERIAL AND METHODS

Twelve consecutive patients (9 male, 3 female) with primary OA and intact cuff but highly deformed glenoids (> 10° retroversion or inclination) were scheduled for a shoulder arthroplasty. Pre-operative 3D planning and PSI were employed to maximize the correction of glenoid inclination and/or version aiming for the implantation of a standard anatomical glenoid component. The 3D virtual planning aimed for the best possible correction of the deformity without compromising the final bone stock or implant stability. That means that the planned position was not fixed but variable case per case. The glenoid deformity was corrected according to the pre-op planning using 2 PSI guides (1 central pin guide, 1 ream guide). After the glenoid correction, antero-posterior stability of the anatomical prosthesis was assessed by translating the humeral head posteriorly. If the head translated 50% posteriorly but reduced spontaneously, the definitive anatomic components were implanted. If the head remained subluxed posteriorly, the procedure was converted to a reversed arthroplasty (Figure 1). Post-operative correction of the glenoid inclination and version was measured and the deviation between pre-operative planning and post-op position of the glenoid baseplate were assessed on CT scans and 3D reconstructions.

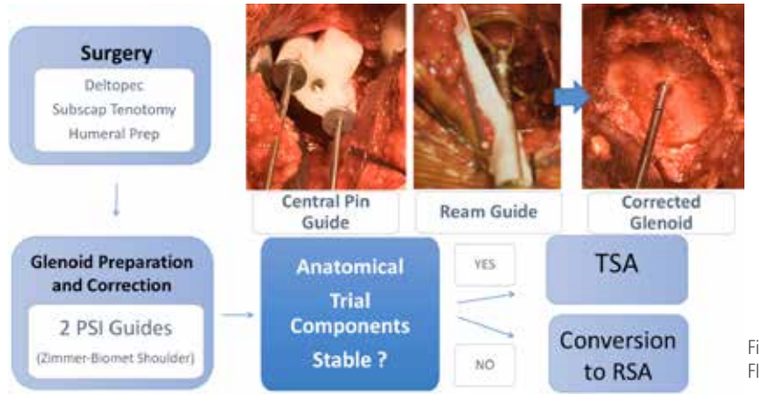

Figure 1
Flowchart

Pre-op 3D Planning

(VIDEO DEMONSTRATION)

- Use the 3D virtual surgery tool (Zimmer Biomet PSI shoulder planner software), which is based on the patient's preoperative computed tomography (CT) scan, to visualize and optimize preparation of the glenoid bone surface and the position and fixation of the implant.
- Assess the patient's native glenoid anatomy and bone stock. Assess glenoid surface inclination and version.
- Virtually position the anatomical glenoid component on the glenoid surface in neutral inclination and version.
- Correct excessive inclination and/or version to what is acceptable (<10° from neutral position) without compromising glenoid bone stock or implant fixation

Surgical Procedure-Glenoid Exposure and Preparation

(VIDEO DEMONSTRATION)

- Dislocate the prepared humerus posteriorly and expose the glenoid to prepare the glenoid surface for component implantation.
- Place retractors behind the posterior and anterior aspects of the glenoid rim and place a small Hohmann retractor on top of the glenoid fossa.
- Release the anteroinferior aspect of the capsule and the long head of the triceps inferiorly.
- Remove the remaining cartilage and remnants of the labrum.
- Specifically prepare the anterosuperior corner of the glenoid rim. This area must be free of interfering soft tissue to allow seating of the PSI pin guide. At this time, compare the native glenoid with the PSI bone model to ensure that all of the soft tissue has been removed and that the PSI pin guide will have a good fit on the glenoid.
- Use the 2 PSI guides to execute the preoperative planning for glenoid component implantation. These include (1) a pin guide for insertion of the central pin in the desired version and inclination; (2) a ream guide, which sets the reaming angle and depth.
- Place the first PSI pin guide on the surface of the glenoid; it should sit tightly on the glenoid surface and be locked in place once it is positioned correctly. The hook should be on the anterosuperior quadrant of the glenoid, and the opening along the bushing should face the posterior side of the glenoid. Hold the PSI pin guide tightly with your fingers and insert the inferior 2.5-mm pin through the central hole of the PSI guide until the depth mark on the pin meets the top of the metal bushing. Then insert the superior 2.5-mm pin through the superior hole in the same manner.
- Remove the bushings and PSI pin guide. Check the insertion points of the 2 pins with the planned position on the bone model
- Create the pilot hole for the glenoid reamers using the 6-mm cannulated drill-bit. Then use the baseplate reamer with the PSI ream guide to prepare the glenoid surface. Ream until the subchondral bone is exposed inferiorly, matching the preoperative plan, and until the PSI ream guide reaches the lateral end of the cannulated straight driver. Compare the reamed glenoid surface with the image provided in the preoperative plan.

RESULTS

The mean age of the patients was 57 years (range, 54 to 68). Pre-op glenoid inclination was 3° (range, -4° to 12°) ; version was -15° (range, -10° to -19°). Five glenoids were classified as B1, 3 as B2 and 3 more as B3 according to the Walch classification 15. Per-operative stability was achieved in all cases, omitting the need for conversion. In all cases a stemless humeral component (Sidus , Zimmer-Biomet) was combined with an all-polyethylene glenoid component (Bigliani-Flatow , Zimmer-Biomet). Post-operative assessment of glenoid components showed mean inclination correction to 1° (range, 0° to 6°), and mean version correction to -7° (range, -2° to -11°). Mean deviation for the final position from the planned inclination was 2° (range, 0° to 7°) and 3° for the planned version (range, 0° to 6°). At a mean follow-up of 26 months (range, 24-35), the Constant score improved from 30 to 69 points, range of motion improved significantly from 100° to 142° for anterior elevation, and from 15 to 40° for mean external rotation. Radiographic lucent lines (RLL) were observed immediately post-op in 2 cases (18%), and in at final follow up in 4 cases (36%) with an increase of the RLL score from 0.36 ± 0.8 to 1.3 ± 2 ($p < 0.001$) without signs of loosening. RLL score was not correlated with dominant side, sex, age, or Constant score.

Figure 2
54 year old RHD male with primary OA. Pre-op 2D and 3D imaging showed retroversion of 16° and superior inclination of 4°. 3D virtual planning aims for acceptable correction of the deformity without compromising glenoid bone stock and fixation of a standard anatomical glenoid implant.

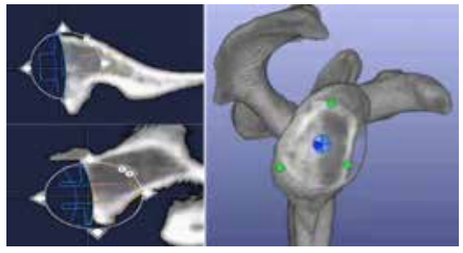

Figure 3
The glenoid deformity was corrected to version of 8° and inclination of 2° with stable fixation of the glenoid component and centering of the humeral head.

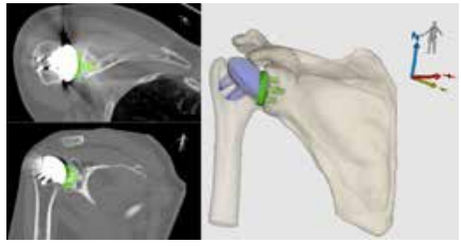

Figure 4

DISCUSSION

Standard total shoulder arthroplasty (TSA) may offer excellent functional results in primary osteoarthritis but requires careful correction of pathologic bone deformity, restoration of the native joint line, and proper soft tissue balancing to ensure glenoid implant stability. Glenoid component malposition, particularly component retroversion, is a significant risk factor for early lucent lines and failure[5-7,16]. Undercorrection of retroversion can result in persistent posterior humeral head subluxation, which causes eccentric loading of the glenoid component and premature loosening[1,5]. Biomechanical studies suggest that this risk can be minimized by placing the glenoid component in less than 10° of retroversion[1].

Asymmetric reaming of the glenoid and glenoid bone grafting are the two most commonly used surgical techniques to address excessive retroversion and glenoid bone loss. More recently, augmented glenoid components that correct pathological retroversion without the need for bone grafting have been introduced (refs). Reverse shoulder arthroplasty is also now increasingly selected for older patients with more advanced posterior glenoid bone loss and biconcavity[10].

Advanced imaging is a valuable tool for preoperative assessment of the deformed glenoid. 3D virtual planning has been shown to accurately for predicting premorbid glenoid version, inclination, and joint line position[8]. Planning also helps the surgeon identify the extent and location of bone loss in the deformed glenoid. This information is valuable in assisting the surgeon to adequately correct the deformity and select the optimal implant to restore native glenoid anatomy, while avoiding peg perforation[8,13,17]. Patient specific instrumentation has been developed to help transfer information from the preoperative planning software to the patient[2,3,8]. The use of patient matched guides have been shown to be accurate and enable the surgeon to precisely execute pre-operatively planned corrections of glenoid deformity[2,3,4,14]. The greatest benefits lie in the elimination of outliers when preparing glenoids with no or minor bone loss, but more specifically in correction of highly deformed glenoids. This may result in less frequent under-correction of version or inclination, less joint line medialization due to over-reaming, and decreased peg perforations[3,4].

A previous study recommended the use of posterior bone grafting or an augmented component when there is more than 16° of preoperative glenoid retroversion. That study suggested correcting glenoid retroversion to 6° rather than 0° in order to minimize joint line medialization and best restore native anatomy[12]. In the current patient population we were able to adequately correct deformity with a mean of 15° of retroversion to an acceptable component position (mean -7°) without compromising glenoid bone stock or centering of the humeral head. Excellent clinical outcomes with a low incidence of radiolucencies around the glenoid component were found at a mean follow-up of 2 years. Correction to a complete neutral position (version and/or inclination) is not preferred in longstanding deformities in osteoarthritic shoulder joints, certainly not at the expense of bone stock or joint line preservation. We prefer moderate correction of the glenoid deformity to less than 10° of retroversion and/or inclination were safe fixation of the anatomic glenoid component is reproducible and centering of the humeral head is secured Augmented glenoid components may be the preferred option for larger deformities > 16° as bone grafting procedures in anatomical TSA or the implantation of an RSA are to be avoided in young, active patients. Longer-term follow will be needed to determine the clinical and radiological outcome of these procedures and my provide more detailed guidelines of the limitations and solutions of glenoid correction procedures.

CONCLUSIONS

3D pre-op planning and PSI guided correction of highly deformed glenoids results in good per-operative antero-posterior stability of an anatomical prosthesis, accurate postop correction of the glenoid deformity and low deviation from the planned position. Long-term follow-up will determine if this technique results in better clinical outcome than bone grafting procedures, augmented implants or RSA.

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43/ REVERSE SHOULDER ARTHROPLASTY: TECHNICAL CONSIDERATIONS & OUTCOMES

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INTRODUCTION

In 2011, 21,692 people underwent reverse shoulder arthroplasty (RSA) in the United States.[1] This procedure is performed to manage a collection of end-stage degenerative, inflammatory, or traumatic pathologies of the shoulder. RSA has demonstrated promising mid-term outcomes.[2-5] Subsequently, these results have led to RSA being used with great frequency and foreseeable stable growth.[1, 6-8] The increase in utilization has resulted in an improved understanding of the anatomy and pathology, as well as, technological advancements in implant design, fixation, and surgical techniques.

In the 1950s, Dr. Charles Neer introduced the use of an anatomical, non-constrained total shoulder arthroplasty to address the treatment of degenerative and traumatic shoulder arthritis in the setting of functional rotator cuff.[2] However, treatment options to address the problem of a deficient or absent rotator cuff remained unanswered. In 1985, Dr. Paul Grammont proposed a reverse-designed prosthesis that shifted the center of glenohumeral rotation medially within the bone of the native glenoid. This medialization of the center of rotation was a revolutionary step in overcoming implant loosening, which was the main cause of failure in previous design iterations. However, several adverse effects including scapular notching, excessive arm lengthening, and infringement of greater tuberosity bone stock were still reported.[10-12] Frankle et al. challenged the logic of a medialized center of rotation, instead opting to place the glenosphere offset from the surface of the glenoid, thus relocating the center of rotation closer to its anatomic location. Through innovative design, appropriate patient selection and rigorous scientific investigation reverse shoulder arthroplasty has been effective in treating patients with various shoulder pathology. Our technique based on over 20 years of clinical experience will illustrate pertinent techniques and corelated outcome of reverse shoulder arthroplasty for varying indications.

METHODS

Primary Reverse Surgical Technique

Patient is position in the beach chair position after receiving general anesthesia. The posterior aspect of the chair behind the operative shoulder is removed. The patient is prepped and draped in sterile fashion. IobanTM (3MTM Medical, Maplewood, Minnesota, US) is typically used to seal of skin to reduce the risk of skin flora contamination into the wound.

A standard deltopectoral incision is made approximately 5 cm medial to the acromioclavicular joint and extended distally and laterally along the deltopectoral groove. Perforated skin vessels are cauterized down to the level of the fascia starting proximal in the interval and the cephalic vein is taken medially with the pectoralis major. The perforating tributaries draining the deltoid as carefully ligated to minimize bleeding. The subdeltoid space with the use of blunt retraction and electrocautery is developed proximal to distal. A Browne deltoid retractor is inserted in that space. The clavipectoral fascia is incised and a plane is developed to the base of the coracoid. A blunt Holman retractor is placed is placed lateral to the conjoined tendon and secured to the drapes with and Alice clamp. The biceps tendon is identified and tenodese with a non-absorbable suture to the upper border of the pectoralis major. The biceps sheath is incised from its sheath and followed proximally through the rotator cuff interval to the level of the glenoid tubercle. A peel is used to remove the subscapularis of the lessor tuberosity. The capsule is continuously removed from the medial aspect of the humerus exposing the humeral head to the level of the posterior cuff with the help of gentle external rotation.

With the humeral head exposed, osteophytes are removed from the anterior and inferior aspect of the humerus in preparation of the humeral head cut. A 135 degree head-neck angle cutting guide is used to make and anatomical neck cut in 30 degrees of retroversion relative to the forearm. Additional osteophytes are removed circumferentially with the use of forward flexion, adduction and external rotation of the humerus.

A sharp retractor is placed on the posterior aspect of the humeral cut surface. A small human retractor is placed superior to the glenoid tubercle. The subscapularis is mobilized to allow for maximum excursion. The axillary nerve is palpated after mobilization. A third retractor is placed between the MGL and the subscapularis tendon superiorly. Using electrocautery, a circumferential capsular release starting from the 2' o clock position excising capsule and

labrum from the glenoid surface. A cobra retractor is placed on the anterior surface of the glenoid.

A 2.0 mm drill is placed perpendicular to the glenoid surface bi-cortically. The drill is removed with a needle driver and the baseplate tap is placed under power to the base of the threads. The tap is then advanced further to the laser line by hand to assess for manual purchase of the baseplate tap into native bone. The glenoid surface is then reamed over the tap to bleeding bone. The tap is then removed and the baseplate is placed in the same trajectory. With the use of a targeting guide peripheral 5.0mm screws are drilled to the appropriate length and depth. A glenosphere appropriate for the patient's anatomy is then placed over then baseplate with engagement of the Morse taper and secured with a set screw.

Attention is then turned to the humerus. With adequate exposure using a Browne-Deltoid Retractor, a sharp Hohmann retractor and a black Derra glenoid retractor, the humeral metaphysis is prepared with an acetabular reamer. The humeral canal is reamed sequentially by manually for appropriate diaphyseal engagement. Four robust non-absorbable sutures are placed laterally to the bicipital grove for repair of the subscapularis tendon. The final humeral stem is inserted in 30 degrees of retroversion. Trial inserts are placed in the humeral component inset shell and the shoulder is reduced and brought through an impingement free range of motion. The trial insert is the removed and the final polyethylene insert is placed. The prosthesis is reduced and trial once more for appropriate tensioning and range of motion. The subscapularis is repaired to using the trans-osseous non-absorbable sutures previous passed in preparation of the humerus. The deltopectoral interval is then closed in a layered fashion

DISCUSSION

Primary Technique Outcomes

Early reports of patients treated with a reverse shoulder arthroplasty for rotator cuff deficiency showed improved clinical outcomes, but unfortunate high mechanical failure of the baseplate secondary to increases forces with a lateralized center of rotation. [13-15] With modification of 5.0 mm locking screws and inferior tilt, 112 patients with a minimum of two-year follow-up demonstrated improved ASES, SST, forward flexion, abduction and external rotation. No mechanical failures of the baseplate were observed.[16] Mulieri et al reported on outcomes of RSA for the treatment of irreparable rotator cuff tears in patients without arthritis of the glenohumeral joint. In this series, a total of 69 patients with either pseudo-paralytic shoulder without pain, pseudo-paralytic shoulder with pain, or greater than >90 of forward elevation with intractable pain were observed postoperatively after RSA with a minimum of 2 year follow up. The entire cohort had significant improvement in ASES, SST, pain reduction measured by VAS scores, and improvement in range of motion in all planes. Greater than 90 percent survivorship was observed all patients over an average of 52 months. [17] Long term follow-up of previous cohort of RSA for the treatment of rotator cuff deficiency, Cuff et al reported a 94% survivorship at 60 months and maintained improvement functional outcome scores and range of motion at a minimum of 10-years.[18-19] These reports of improved survivorship and clinical outcomes has resulted in an increase in utilization of RSA in younger patients with severe pathology. Otto et al reported on results of 67 patients who underwent reverse shoulder arthroplasty under the age of 55. All patients had significant improvement in ASES scores and SST scores with a high implant retention rate at final follow up.[20]

Reverse Outcomes in Osteoarthritis with Intact Rotator Cuff

Reverse shoulder arthroplasty can reliably treat patients with great outcomes suffering from glenohumeral osteoarthritis with an intact cuff. Often B2 and B3 glenoid morphologies are often difficult to achieve stable glenoid fixation. With possible unreliable results of eccentric reaming, we often convert 10% of our total shoulder arthroplasty to reverse shoulder arthroplasty.[21] Steen et al compared 24 patients with glenohumeral arthritis who were converted intraoperatively to a reverse shoulder arthroplasty due to difficulties placing secure glenoid implant to 96 matched patients that underwent total shoulder arthroplasty.[22] Postoperative assessment revealed similar range of motion, ASES scores and simple shoulder test between the two groups. Additionally, over two year follow up neither group required a revision surgery. However, radiographic lucency was observed in 5 patients who underwent total shoulder arthroplasty. Most recently, Cox et al compared 19 patients who underwent bilateral shoulder arthroplasties, reverse on one side and an anatomic on the other.[23] Although they did find greater internal rotation in the TSA side, patients achieved similar clinical results forward flexion and external rotation. There were no differences found in postoperative ASES or SST scores, and 68.4% of patients preferred the RSA side over the TSA shoulder. These studies confirm our clinical findings and give further evidence for the use of RSA to treat osteoarthritis.

Acute Fracture

Anatomic reduction of the tuberosities in proximal humerus fractures treated with RSA are often difficult to achieve. Malpositioning and unreduced tuberosities can often yield poor outcomes.[24] Modification of the technique for primary reverse allows for the facilitation of appropriate reduction and healing of the tuberosities to the prosthesis. Through a standard deltopectoral approach the biceps is identified and tenodesis to the pectoralis major. After mobilization of the subdeltoid, subacromial, and sub-coracoid spaces, 4 non-absorbable sutures are placed into the greater tuberosity, 2 into the lesser tuberosity and 3 into the humeral shaft using a 2.0mm drill. After placement of final components, the greater tuberosity is reduced and fixed to the shell with 2 horizontal sutures. The lesser tuberosity is fixed to the shell with 2 horizontal sutures, and the greater tuberosity is reduced to the shaft with 2 sutures with the humeral shaft for vertical fixation. Finally, the lesser tuberosity is secured to the shaft with 1 suture for vertical fixation, and 2 sutures are used to secure the tuberosities together in a cerclage fashion. (Insert Figure).

Malunion

The technical approach for implantation must be modified for patients with severely malunited fractures of the proximal humerus. The socket of the implant should be centered in the deformity. The acetabular reamer should be placed freely within the deformity. Implantation of the humeral stem often requires increase retroversion >30 degreees. Excess bone should be removed to increase the impingement free range of motion. Willis et al reported outcomes of 19 patients with malunited proximal fractures, all of whom required modifications in humeral stem preparation.25 All patients had significant improvement in postoperative ROM (forward flexion, abduction, and external rotation), functional outcome scores, and decreased pain scores.

Native Glenoid Bone Loss

Eccentric bone loss provides a challenge component to secure fixation of the baseplate in reverse shoulder arthroplasty. Due to the severity of bone loss limiting contact with the implant that may induce micromotion compromising fixation potentially leading to early failure.26 Use of the alternative scapula spine line can allow for better fixation of the baseplate to native bone, with or without the augmentation of glenoid bone grafting. Klein et al reported on the results of 56/143 shoulders with abnormal glenoid bone stock with baseplate fixation via an alternative spine line. 27 Twenty-two of twenty-six shoulders had severe glenoid bone loss requiring bone grafting. At two year follow up, no mechanical failure or resorption of the bone graft were observed. This modification for glenoid bone preparation can be useful in patients prone to eccentric and excessive glenoid erosion.

Bone Loss Secondary to Failed Arthroplasty

Severe glenoid bone loss can also occur in the setting of failed shoulder arthroplasty. Modification of glenosphere selection is incumbent on assessment of a contained versus uncontained glenoid defect. Contained glenoid defects with an intact cuff are treated with 32N or 32 - 4 in an attempt to restore adequate soft tissue tensioning, allowing maximum impingement free ROM without significant distal displacement. Uncontained glenoid defects with an intact cuff are treated with larger glenospheres, which result in improved load sharing and will theoretically protect the graft from resorption. However, this often leads to an imbalance of soft tissue tension due to lateral arm displacement. Modification of this technique to accommodate for large defects can yield promising clinical improvements in revision arthroplasty cases of failed RSA and failed TSA.[28-30]

Proximal Humeral Bone Loss

Proximal humeral bone loss is often common of failed arthroplasty secondary to a multitude of causes including: humeral stem loosening, periprosthetic fracture and infection. Use of a proximal humeral prosthetic allograft can improve stability of construct, restoration of humeral height and improve deltoid wrapping. It has been reported that these measures will increase the likely hood of improved motion postoperatively.31 Levy et al have reported use of proximal humeral allografts for the treatment of failed hemiarthroplasty for proximal humeral fractures. Their results suggest improved functional outcome scores, as well as, range of motion in forward flexion and abduction.32 Chacon et al as reported improved functional outcome scores and range of motion in patients treated with a prosthetic allograft for revision arthroplasty with short to midterm follow up.33 Our modified technique of a step cut humeral allograft osteotomy with cerclage wiring and/or plate fixation with cementation is preferred for improved stability.

RSA Instability

Instability after reverse shoulder arthroplasty can be a complex and multifactorial problem, that often involves loss of compression, loss of containment, and impingement. This system's lateral center of rotation design as well as various glenosphere sizes have resulted in 80 percent stability revision cases due to instability at 2 year follow up. 34

CONCLUSION

Altivate reverse total shoulder arthroplasty has been the product of 20 years of surgical experience, evolution of design, and extensive biomechanical and clinical research. It has application for use in various shoulder arthroplasty indication, ranging from proximal humerus fracture treatment to reverse arthroplasty. The options available for this prothesis should be explored as use in a shoulder surgeons armamentarium.

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44/ SALVAGE OF CHRONIC SHOULDER DISLOCATIONS

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Despite improved access to healthcare, advances in understanding of shoulder trauma, and widespread use of advanced imaging techniques, occasionally patients continue to present to the shoulder surgeon with a dislocated glenohumeral joint months or years after the index injury.(1, 2) Chronic unreduced dislocations of the shoulder were characterized in detail by Carter Rowe in 1982,(3) and a number of advances have occurred in the management of these injuries over the last 40 years, most notably the widespread adoption of reverse shoulder arthroplasty.(2)

Chronic dislocations may be anterior or posterior. Chronic posterior dislocations are more common, since acute locked posterior dislocations are more often missed. (4) Anterior and posterior chronic dislocations are quite different. In posterior chronic dislocations, most of the times the majority of the bone loss occurs on the humeral side, and it increases over time as patients attempt to regain motion as the locked humeral head hinges on the posterior glenoid. The rotator cuff is more often intact. Open reduction of a locked posterior dislocation for either reconstruction or arthroplasty is associated with a substantial risk of iatrogenic intraoperative fracture of the humeral shaft.

In anterior chronic dislocations, the humeral head defect is oftentimes less pronounced, but the humeral head becomes very osteopenic and fragile. The anterior aspect of the glenoid loses bone over time. Very commonly, there is a large posterosuperior rotator cuff tear associated with the injury. The chronically dislocated anterior humeral head is in close proximity to the brachial plexus and subclavian vessels, and scarring to the vessel walls has the potential to lead to dangerous bleeding at the time of surgery.

Even though there are isolated case reports of reasonable function without further treatment in patients with a chronic dislocation, (5) most patients with a chronic anterior or posterior shoulder dislocation have enough pain and functional limitations to benefit from surgical reconstruction. We will separately discuss anterior and posterior chronic dislocations.

SALVAGE OF CHRONIC POSTERIOR DISLOCATIONS

Locked posterior dislocations may be difficult to recognize on plain anteroposterior x-rays of the shoulder, especially when they are not taking perpendicular to the face of the glenoid (Grashey's view). The axillary x-ray and advanced imaging (computed tomography or magnetic resonance) will show the humeral head dislocated posterior to the face of the glenoid. Bone loss on the humeral head and glenoid is best assessed on computed tomography (Figure 1).

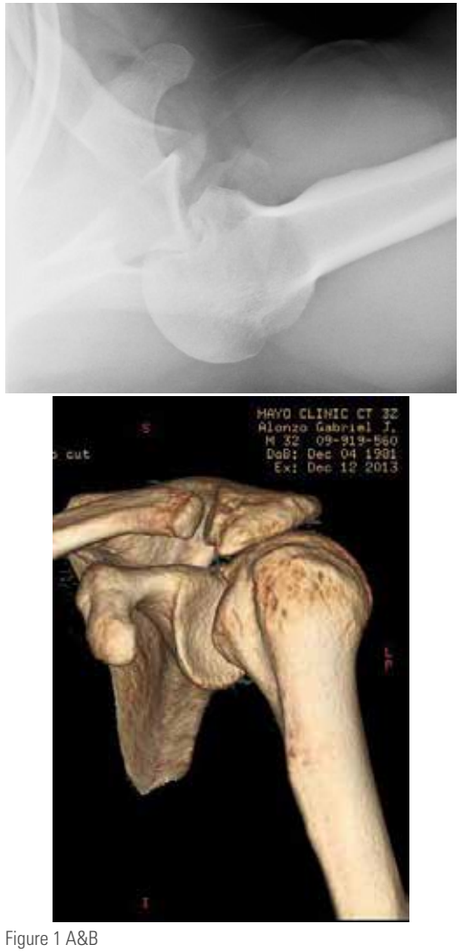


Figure 1 A&B
Axillary xray (A) and three-dimensional rendering of a CT scan (B) in a patient with locked posterior dislocation

Treatment options for the salvage of chronic locked posterior dislocations include closed reduction, open reduction with capsular plication, transfer of the tendon of the subscapularis or the lesser tuberosity to the humeral head defect, osteoarticular allograft, hemiarthroplasty, total shoulder arthroplasty, and reverse total shoulder arthroplasty. Most of the times, patients with a locked chronic posterior dislocation present with too much bone loss to restore stability with either closed reduction or open reduction and capsular plication.

Lesser tuberosity transfer

In chronic posterior dislocations, oftentimes there is a humeral head defect just medial to the lesser tuberosity. After closed or open reduction, this humeral head defect may engage with the posterior glenoid rim in internal rotation facilitating recurrent dislocations. McLaughlin came up with the idea of detaching the tendon of the subscapularis off the lesser tuberosity for exposure, performing an open reduction of the posterior dislocation, and inserting the tendon of the subscapularis into the humeral head defect. Neer modified this procedure to transfer the lesser tuberosity; potential benefits of the lesser tuberosity transfer over transfer of the subscapularis tendon include providing bone to fill the defect as well as the potential for bone-to-bone healing (Figure 2).

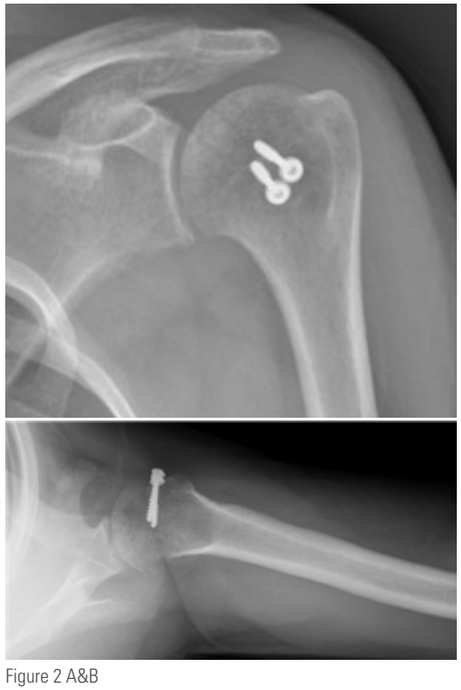


Figure 2 A&B
Anteroposterior (A) and axillary (B) radiographs after lesser tuberosity transfer for a locked posterior dislocation

There are not many recent reports on the outcome of transfer of the lesser tuberosity for posterior shoulder instability. Demirel et al reported on 13 shoulders surgically managed using the Neer modification of the McLaughlin procedure.(6) The underlying diagnosis was a locked posterior dislocation in 8 shoulders and recurrent posterior dislocations in 5 shoulders. Nine patients had underlying epilepsy. The average defect size in these shoulders was 27%, ranging from 20% to 40%. At most recent follow-up, there were no recurrent dislocations, average elevation was 163 degrees, active external rotation was 70 degrees, the mean ASES score was 78 points, and the mean Constant score was 58 points. A recent systematic review confirmed good outcomes in well-selected patients.(4)

Osteoarticular allografts

Use of a structural osteoarticular allograft represents an appealing alternative for patients with chronic posterior dislocations and a larger humeral head defect that cannot be properly reconstructed with the lesser tuberosity. Gerber first reported 4 shoulders with a locked posterior dislocation reconstructed using a femoral head allograft. (7) No shoulder redislocated and patients experienced good overall outcomes, although one shoulder developed asymptomatic avascular necrosis. More recently, Diklic et al reported on 13 locked posterior dislocations treated with a structural femoral head allograft. (8) Ten patients had underlying seizure disorder, and the humeral head defect ranged between 25% and 50%. There were no recurrent dislocations, and patients experienced good functional outcomes, with one case of documented avascular necrosis.

Anatomic arthroplasty

For shoulders with extensive humeral head defects, replacement of the humeral head with a hemiarthroplasty was the salvage procedure of choice until the introduction of reverse shoulder arthroplasty. Addition of a glenoid component (total shoulder arthroplasty) is considered when the glenoid articular surface is damaged. Wooten et al. reported on 32 shoulders (18 hemiarthroplasties and 14 total shoulder arthroplasties) performed for a chronic posterior dislocation and followed for a mean of 8.2 years.(9) At most recent follow-up, mean active elevation was 90 degrees and mean active external rotation 50 degrees. However, the rate of revision surgery was 28% (instability 3, deep infection 2, glenoid pain 2, and nonunion of an intraoperative fracture 1 shoulder). For patients with no reoperations, 78% were subjectively satisfied (Figure 3).

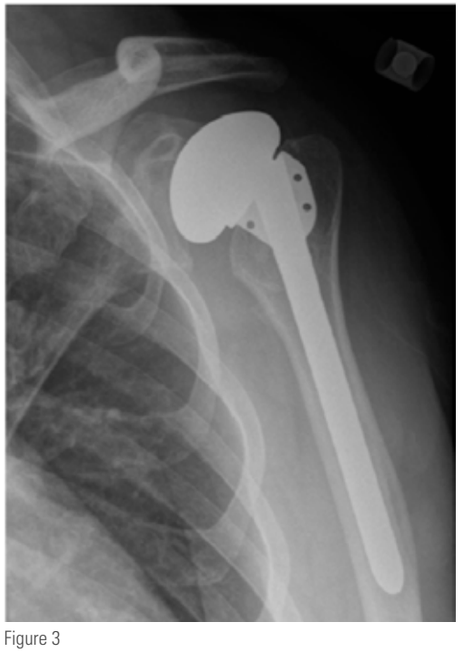


Figure 3
Good radiographic outcome after shoulder hemiarthroplasty for a locked posterior dislocation

Reverse arthroplasty

Reverse arthroplasty has the potential for providing adequate fixation when glenoid bone stock is compromised and may provide better postoperative stability as compared to anatomic arthroplasty due to the semiconstrained nature of the implant. However, to date there is very limited information on the outcome of reverse shoulder arthroplasty for locked posterior dislocation. One study by Raiss et al reported on 22 reverse shoulder arthroplasties for locked dislocations, but only 4 were posterior, with the remaining 18 being anterior. (1) More studies are needed to better understand the outcome of reverse shoulder arthroplasty specifically for locked posterior dislocations.

SALVAGE OF CHRONIC ANTERIOR DISLOCATIONS

Chronic anterior dislocations are typically easier to identify on plain radiographs. Sometimes, these patients have undergone several closed reductions, but the glenohumeral joint will just not remain reduced due to a combination of bone loss and compromised soft-tissues. Large posterosuperior cuff tears are often present, and the lack of restrain from the posterior soft-tissues contributes to persistent anterior instability (Figure 4).

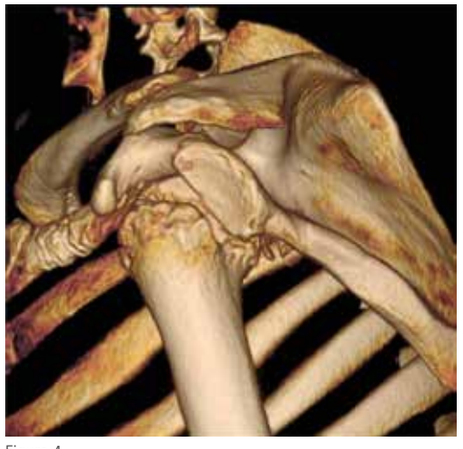


Figure 4
Computed tomography with three-dimensional reconstruction shows a locked anterior shoulder dislocation

Options for reconstruction include closed reduction, closed reduction with plication or reconstruction of the anterior capsule and cuff repair, open reduction and bone augmentation, and shoulder arthroplasty. As mentioned earlier, some patients with a locked anterior dislocation are elderly and frail, and there are several reports that include patients treated nonoperatively. (10) Although soft-tissue reconstructions using allograft augmentation of the anterior glenohumeral joint capsule have been reported, (11) most chronic dislocations cannot be rendered stable by soft-tissue procedures.

Glenoid bone reconstruction

Reconstruction of the deficient anterior rim of the glenoid is oftentimes considered for patients with recurrent anterior instability, either through a coracoid transfer procedure or using structural osteoarticular allograft.(12-14) However, the results of glenoid bone reconstruction procedures have been less successful in patients with chronic locked anterior dislocations. One failure after coracoid transfer was reported by Flatow et al in 1993. (10) More recently, Li and Jiang reported on the outcome of the Latarjet procedure in a mixed group of patients with chronic anterior dislocation of their native shoulder or anterior dislocation of a previously performed anatomic arthroplasty.(15) There were 25 shoulders included in their study, with 10 additional shoulders lost to follow-up. The overall redislocation rate was 48%, and it was particularly high (80%) when performed for an anteriorly dislocated hemiarthroplasty.

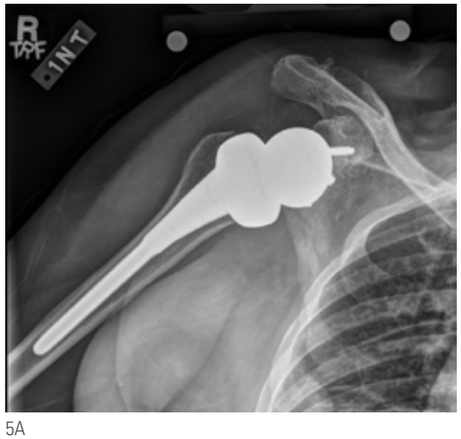
Shoulder arthroplasty

The majority of patients that need surgery for a locked anterior shoulder dislocation have substantial destruction of the articular cartilage of the humeral head and are often

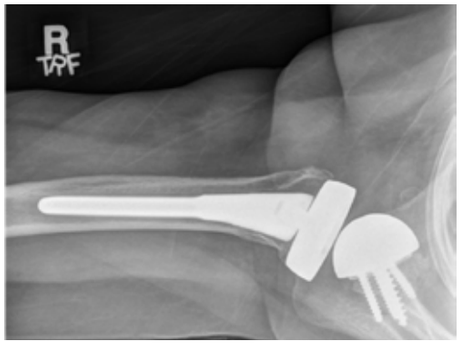
considered for shoulder arthroplasty.(1, 2, 10, 16, 17) Statz et al reported on 19 locked anterior dislocations treated with shoulder arthroplasty. (2) Implants used included hemiarthroplasty in 3 shoulders, anatomic total shoulder arthroplasty in 7 shoulders, and reverse shoulder arthroplasty in 9 shoulders. Recurrent instability was reported in 50% of the anatomic arthroplasties (4 total shoulders and 1 hemiarthroplasty). One additional hemiarthroplasty developed incapacitating pain secondary to progressive glenoid erosion. The 9 reverse shoulder arthroplasties included in this study resulted in reasonable functional improvements, with a mean ASES score of 76 points, a mean simple shoulder test of 7.4 points, and a subjective shoulder value of 55%. Motion at most recent follow-up included elevation to 106 degrees, external rotation to 46 degrees, and internal rotation to the sacrum. Two intraoperative fractures occurred when performing reverse for a locked anterior dislocation.

In a separate study, Rais et al. reported on 22 reverse shoulder arthroplasties performed for locked dislocations; the direction of dislocation was posterior in 4 and anterior in 18 shoulders.(1) Shoulder arthroplasty was associated with reasonable outocomes (mean flexion 103 degrees, mean external rotation 14 degrees, and a mean Constant score of 57 points). However, the reoperation rate was 27%, and glenoid loosening was the most common reason for revision (4 shoulders).

One of the issues with performing a reverse shoulder arthroplasty in patients with a locked anterior dislocation is the amount of bone missing in the anterior aspect of the glenoid, which sometimes can be pretty substantial. In these circumstances, obtaining primary stability and ingrowth can be particularly challenging, which might explain the relatively high glenoid failure rate reported by Rais el al.(1) This may be an ideal indication for use of the so-called alternative scapular spine centerline of Frankle. (18) (Figure 5)



5A



5B

Figure 5 A&B
Anteroposterior (A) and axillary (B) radiographs after reverse shoulder arthroplasty implanted along the alternative scapular spine centerline

SUMMARY

Surgical management of locked anterior and locked posterior dislocations can be a challenge secondary to soft-tissue contracture, capsule and cuff insufficiency, and bone loss. Posterior locked dislocations typically present with a large humeral head defect; open reduction of the dislocation at the time of surgery is particularly difficult, and the risk of iatrogenic humeral shaft fracture is real. Anterior locked dislocations leave the humeral head in dangerous close proximity to the subclavian neurovascular structures, and anterior glenoid bone loss tends to be substantial; in addition, the posterosuperior cuff is oftentimes torn.

For locked posterior dislocations, when the humeral head defect is under 25% good results may be obtained with Neer modification of the McLaughlin procedure. For defects between 25% and 50%, structural osteoarticular allografts have promising results, although AVN of the graft may occur. Humeral head defects larger than 50% are typically managed with anatomic or reverse arthroplasty, depending on the condition of the cuff, glenoid bone loss, and intraoperative soft-tissue balance.

For locked anterior dislocations, anatomic arthroplasty has been reported to be associated with a 50% rate of redislocation. As such, reverse arthroplasty is currently favored. However, the complication rate of reverse for locked dislocations is higher than other diagnosis such as cuff tear arthropathy.

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45/ REVERSE SHOULDER ARTHROPLASTY IN PATIENTS WITH PREOPERATIVE DELTOID IMPAIRMENT

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ABSTRACT

The indications for reverse shoulder arthroplasty (RSA) continue to expand. A normally functioning deltoid has been considered a prerequisite to implantation of a RSA since the prosthesis depends upon the function of the deltoid and impairment of that may increase the risk of dislocation. However, clinical results suggest that partial preoperative deltoid impairment, in certain circumstances, is not an absolute contraindication to RSA. In fact, with partial deltoid insufficiency, RSA can still yield reliable improvement in functional outcome without excessive risk of postoperative complications.

INTRODUCTION

During evolution the permanently orthograde posture has freed the human shoulder girdle of its quadruped functions. The anterior limbs became the upper limbs with the characteristics of a non-weight-bearing joint. Major bony and muscular adaptations occurred.[1] The scapulohumeral complex underwent drastic changes to facilitate prehension, leading to major bony and muscular modifications. A relative atrophy of the supraspinatus muscle occurred, as illustrated by a decrease in the scapular index.[2,3] The decrease in the effectiveness of the latter muscle was at the same time compensated for by the increase in size, mass, and lateral extension of the acromion process. The progressive distal migration of the point of insertion of the deltoid muscle and lateralization of the acromion indicates the more dominant position occupied by the deltoid with strengthening in particular of the middle deltoid abduction component.[4]

The glenohumeral joint is highly mobile and relatively unconstrained. Stability of the joint relies upon concavity-compression whereby the rotator cuff exerts a compressive force of the humeral head upon the glenoid. In the absence of concavity-compression, the unopposed contraction of the deltoid creates a force vector that displaces the head superiorly rather than in abduction. Depending on the type of rotator cuff lesion, a patient may present with pseudoparalysis . Several options exist to manage such loss of function of the rotator cuff. The most reasonable, whenever possible, is to repair the rotator cuff. Good results are obtained in the vast majority of the cases[5-9] with healing of the rotator cuff on the tuberosities[10] and even reversal of pseudoparalysis.[11,12] In some circumstances, however, rotator cuff repair is contraindicated (e.g. advanced glenohumeral arthritis) or technically impossible (e.g. advanced fatty degeneration). In these settings, the power of the deltoid can be harnessed through a reverse shoulder arthroplasty (RSA) in order to regain active shoulder elevation.

In order to provide active forward elevation above 90°, the abduction role of the deltoid has to be increased. This can be obtained by several mechanisms, such as an osteotomy of the scapular spine[13] or more commonly by medializing the center of rotation the glenohumeral joint.[14] RSA inverts the ball-and-socket relationship of the shoulder joint. This concept, developed by Grammont and Baulot,[13] medializes and lowers the center of rotation which increases the lever arm of the deltoid muscle and allows recruitment of more anterior and posterior deltoid fibers. The medialization increased the deltoid moment arm up to 20%, and an inferior move increased the efficacy of the deltoid up to 30%.[15] This relationship also re-tensions the deltoid and restores stability to the glenohumeral joint so that there is a stable fulcrum for active forward elevation. [16] Thus in the setting of a severely deficient rotator cuff, RSA may permit patients to achieve good functional results.[16,17] Stability of a RSA, however, depends upon the semi-constrained design as well as the surrounding muscle forces. Thus, if the deltoid is impaired, functional outcome may be compromised and the risk of postoperative dislocation after RSA may theoretically increase.

After the benefits of RSA were seen for rotator cuff arthropathy, the indications for this prosthesis have been expanded to more complex diagnoses.[17-22] Based on the biomechanical understanding that RSA depends upon the deltoid for function, a normally functioning deltoid was initially considered a requirement for implantation.[23] However, partial deltoid impairment may not be an absolute contraindication to RSA.

The present chapter will focus on the classification of deltoid impairment according to different parts of deltoid insufficiency, determine the functional outcome and risk of dislocation for RSA, and describe our current therapeutic technique of RSA in this setting.

DEFINITION, CAUSES, AND CLASSIFICATION OF DELTOID IMPAIRMENT

The deltoid is critical for shoulder motion and any pathology involving this muscle is highly detrimental to normal glenohumeral function. It generates over 50% of the force necessary to elevate the arm in scapula plane in a normal shoulder and is the only muscle remaining to provide an abduction moment in patients with massive rotator cuff tears.[24] We define deltoid impairment as any condition which compromises its physiological function. Such impairment may be permanent or transient and can occur from a variety of conditions.

The deltoid muscle may be shortened upon itself and lose function by disruption of normal length-tension relationships (Figure 1).

Effectively, as the Blix curve describes, maintenance of length is required for a muscle to generate adequate tension.[25] Therefore shortening either by proximal migration of the deltoid insertion (rotator cuff arthropathy) or distal migration of the origin (scapular spine fracture) will compromise deltoid function. Proximal migration in particular can be considered a transient cause of deltoid impairment since it can be treated with RSA. Distal migration, on the other hand, may be permanent or transient depending on the situation.

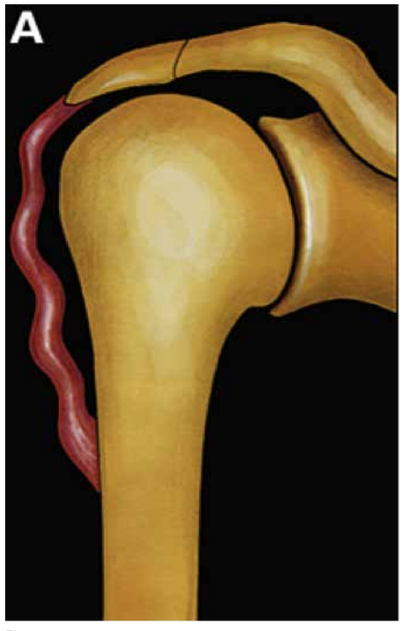


Figure 1
Proximal migration of the humeral head leads to a lack of deltoid tension

In the most severe conditions, part or all of the deltoid muscle may be completely absent. Such permanent impairment is rare but may be observed following deltoid muscular flap transfer (for irreparable rotator cuff tears, Figure 2)[26-28] or following tumor resection (Figure 3).

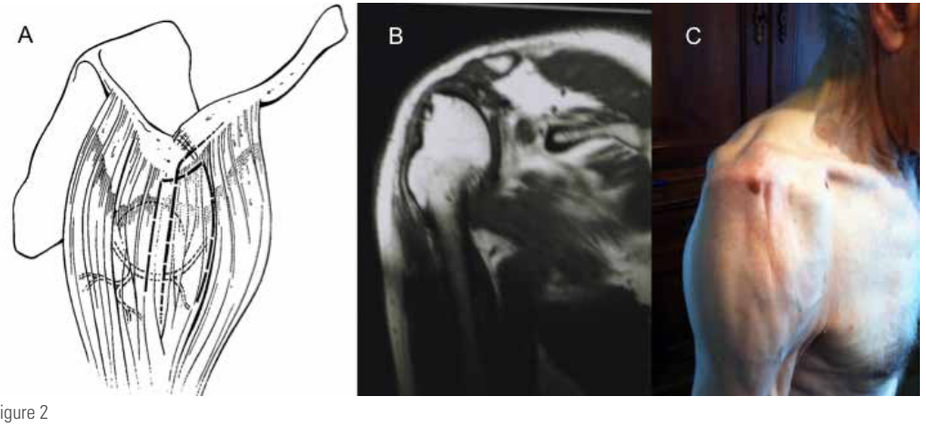


Figure 2
Status after a left deltoid muscular flap transfer for irreparable rotator cuff tears. A: Schematic drawing of the surgical technique (with permission of Gazielly D.). B: Frontal MRI demonstrates absence of the deltoid muscle laterally. C. Clinical photo demonstrating atrophy of the anterior and middle deltoid

One of the most common forms of deltoid impairment seen clinically is disruption of the muscle origin (without removal of the entire muscle belly). This most commonly occurs in the postsurgical setting after an open rotator cuff repair in which a deltoid split approach is used and part of the deltoid origin is take-down to gain exposure (Figure 4).[29] Failure of the deltoid to heal back to the acromion can easily be appreciated clinically by a defect to palpation.

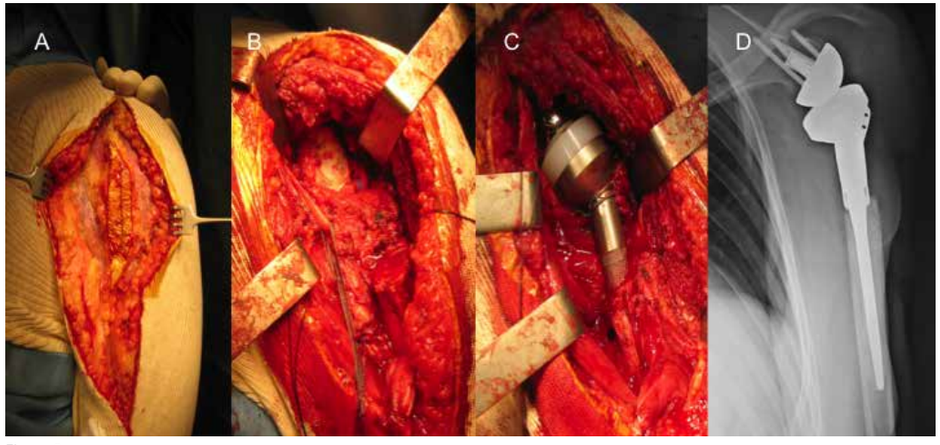


Figure 3
A: Intraoperative view of a left anterior deltoid resection in the context of proximal humerus neoplasm. Isolation of the anterior deltoid through which an open biopsy had previously been performed. B: Resection of the entire anterior deltoid and proximal humerus. C: Intraoperative view following implantation of a RSA. D: Postoperative anterior-posterior radiograph.

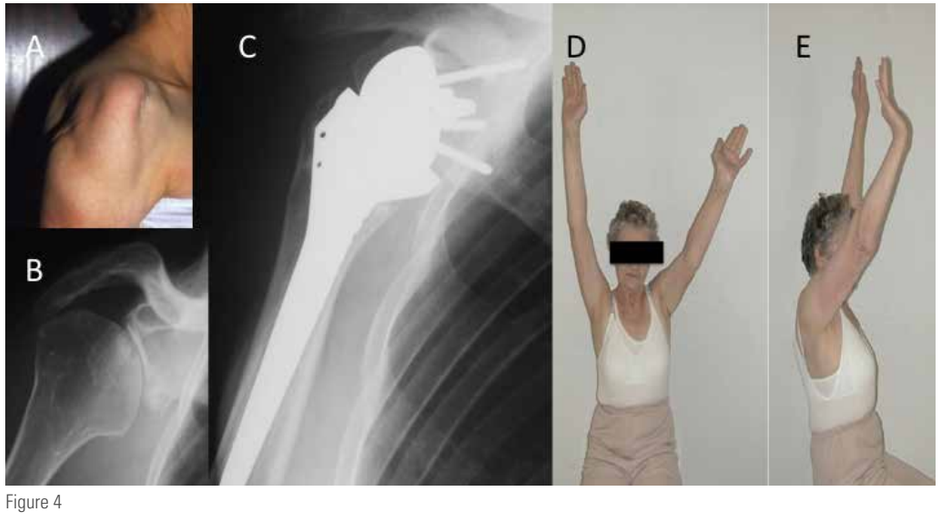
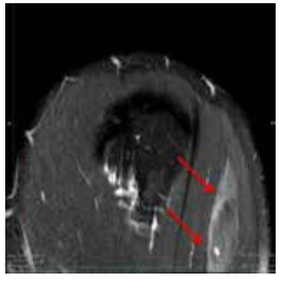


Figure 4
Sequelae of a right open rotator cuff repair involving violation of the deltoid insertion. A: clinical appearance with an anterior deltoid with severe atrophy. B: Anterior-posterior radiograph demonstrating rotator cuff arthropathy. C: Postoperative anterior-posterior view of the RSA. D and E: Coronal and sagittal views of postoperative anterior forward elevation



Additionally, deltoid insertion disruption can occur through chronic attritional rupture as in chronic rotator cuff arthropathy with anterosuperior escape[30,31,] or following trauma (Figure 5).[32,33]

Figure 5
Evaluation in an acute phase of left posterior deltoid insertion disruption on T2 weighted fat saturated MRI arthrogram sagittal sequences revealed an edema (red arrows) propagating into the muscle.

The deltoid muscle may be globally impaired in the setting of persistent denervation,[34] grade 3 or 4 fatty infiltration,[35] previous surgical approach (Figure 6), trauma (Figure 7), post radiation syndrome, or myopathy (myositis, Parkinson, Duchenne muscular dystrophy, etc.).[36]

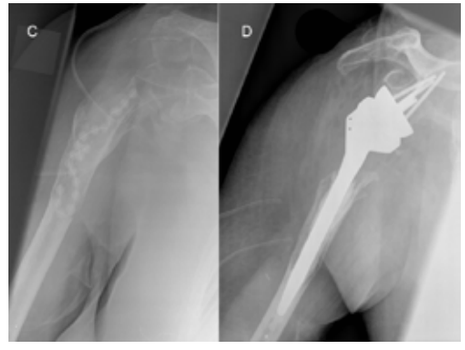


Figure 6
Case illustration. A 54 year old man with a previous bilateral below knee amputation due to diabetes mellitus sustained a motor vehicle accident. A) A hemiarthroplasty had been initially implanted for a four-part fracture of the right proximal humerus. B) The patient developed a deep infection that finally required removal of the prosthesis 3 years later. The patient suffered from consequent pain and was unable to walk with crutches. C) A RSA was implanted a year later. D) A lack of anterior structures (subscapularis, pectoralis major, conjoint tendon) led to an episode of instability. E) X-ray after revision surgery with placement of a thicker polyethylene spacer D) At one year follow-up, the patient was able to walk with two crutches. F) Active anterior elevation was limited to 40° but the patient was satisfied with the result.

Figure 7
Preoperative (A, anterior-posterior and B, lateral scapular views) and post RSA (C anterior-posterior view) of a right shoulder after a gunshot in a patient that presented post-traumatically with global neurological impairment including the axillary nerve.

Finally, in the largest series on deltoid impairment with RSA published to date, the cause of impairment remained obscure/undetermined in 3 on 49 patients (Table 1).[37]
Once the etiology is determined, the deltoid impairment should be then classified according to its location and extent. Lädermann et al.[37] proposed a classification for deltoid impairment based on location: type 1 corresponds to an impairment localized anteriorly, type 2 an anterior and middle one, type 3 involves only the middle deltoid, and type 4 is a global impairment (Figure 8). As discussed subsequently, this classification related to prognosis with type 4 in particular having a poorer function following RSA.

Demographics	Shoulders (N = 49)
Diagnosis*	
Trauma sequelae	13 (27%)
CTA (Hamada and Fukuda 3 to 5)	9 (18%)
RCT (Hamada and Fukuda 1 or 2)	8 (16%)
Revision shoulder arthroplasty	13 (27%)
Dislocation arthropathy	6 (12%)
Reason(s) for deltoid impairment (multiple reasons possible) †	
Post traumatic without surgery	4
Post surgery	25
Axillary nerve lesion	9
Resection or muscular flap transfer	5
Post radiation	2
Deltoid avulsion	3
Unknown	3
Abbreviations: CTA, cuff tear arthropathy; N, number; RCT, rotator cuff tear.	

Table 1
Etiologies of deltoid impairment in the series of Lädermann et al.70
*The values are given as the number, with the percentage in parentheses.
† The values are given as the number.

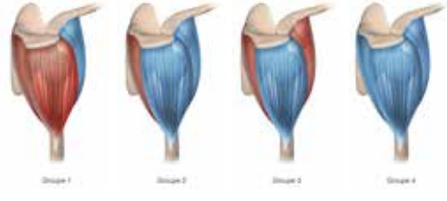


Figure 8
Deltoid impairment base d on location: type 1 corresponds to an impairment localized anteriorly, type 2 an anterior and middle one, type 3 involves only the middle deltoid, and type 4 is a global impairment.

RESULTS

Glanzmann et al. first published a case report of the results of a RSA after deltoid muscle flap transfer.[27] At two years follow-up, the patient was satisfied and had a Constant score of 62 points, suggesting that the entire deltoid may not be necessary for a successful outcome. Tay and Collin also described successful results of a RSA implanted in the setting of an irreparable rupture of the middle portion of the deltoid muscle.[28] No intra- or postoperative complication was noticed. At two years follow-up, the patient was pain free, had active anterior elevation of 150°, and the Constant score was 65 points. Gulotta et al. reported in their biomechanical study that scapular plane elevation may still be possible following an RSA in the setting of anterior deltoid deficiency. When the anterior deltoid is deficient, there is a compensatory increase in the force required by the subscapularis and middle deltoid.[38] In this condition, surgeons should focus on preserving the subscapularis as much as possible during approach of RSA. Whatley et al. reported three cases who had postoperative rupture of the anterolateral deltoid following failed mini-open or open rotator cuff repairs. Successful repair of the deltoid was achieved using a transosseous suture repair in all three patients.[39] Essilfie et al. presented a case with deltoid failure after anatomical total shoulder arthroplasty (TSA) revised with RSA. His ASES score after RSA was better than historical outcomes for resection arthroplasty and glenohumeral arthrodesis.[40] Lattisimus dorsi muscle trasnsfer can also provide an augmentation in patients with deltoid insufficiency.[41,42] Dosari et al. presented a patient with a history of gunshot injury and loss of most of his shoulder bony and muscular structures. Due to deltoid muscle deficiency, the patient underwent lattisimus dorsi muscle flap followed by RSA with successful result.[41] Deltoid reconstruction at the same time of RSA is also a viable choice as a salvage procedure for patients with deltoid deficiency.[43] Marinello suggested if less than 50% of any part of the anterior or middle deltoid was involved (≤3 cm), reattachment or reconstruction was not needed. If all of the anterior and/or middle deltoid were involved, then reattachment or reconstruction was indicated.[43]

In a multicentered study, Lädermann et al. reviewed 49 patients (49 shoulders) at a mean of 38 ± 30 months postoperative following RSA in the setting of deltoid impairment.37 The indications and etiologies are summarized in Table 1. Postoperative complications occurred in nine (18%) patients, including two postoperative dislocations and two acute postoperative neurological lesions. Five (10%) patients required additional surgery. The functional results are summarized in Table 2.

	Pre-op	Post-op	Gain	P†
Range of motion in degree ‡				
AFE	50 ± 38	121 ± 40	64	< .0001
AER at side	5 ± 21	12 ± 16	7	.8438
Constant score ‡	24.8 ± 12.1 (2-51)	58.0 ± 16.7 (16-83)	33.2	< .0001
Satisfaction (%)	NA	98%		
SANE N=29 ‡	NA	70.9 ± 17.0 (10-95)		

Table 2
Preoperative vs. final follow-up measures
AFE, active forward elevation; AER, active external rotation; †, P values are from paired t-tests; ‡The values are given as the mean, the standard deviation with the range in parentheses.

Active forward elevation and Constant score improved significantly. However, these values were significantly lower for patients suffering from global deltoid impairment (type 4) compared to types 1 through 3. The mean postoperative forward elevation was lower in the setting of global deltoid impairment (70°) compared to partial impairment (127°, 136° and 125°, groups 1-3 respectively) (P=.002). The postoperative Constant score was lower in the setting of global impairment (41) compared to partial impairment (57, 63 and 68, groups 1-3 respectively) (P=.006). Overall, the rate of patient satisfaction was 98% at final follow-up.[37]

More recently, Schneeberger et al. retrospectively reviewed the outcome of 19 patients treated with RSA after failed deltoid flap reconstruction.44 They noticed a high rate of complication (37%), including one instability. Nonetheless, at a mean follow-up of 4.5 years, only two patients had moderate to severe pain, all patients regained anterior active elevation above 90°, and 15 of 19 patients were very satisfied.

In summary, the literature demonstrates that RSA is feasible in the setting of deltoid impairment. The complication rate and technical complexity is significant as most patients have had previous surgery. However, functional improvement is attainable, particularly if the deltoid impairment is only partial.

PREOPERATIVE PLANNING

A meticulous examination should be performed prior to considering RSA in the setting of deltoid impairment. Inspection is performed to assess for previous scars, deltoid dehiscence, and atrophy to estimate the extent to which the deltoid is impaired. Strength testing examination includes the deltoid and rotator cuff. The subscapularis (belly press[45] and bear hug[46]), infraspinatus, and teres minor (hornblower's maneuver)[47] should be assessed. Notably, candidates for RSA in our series had to have manual deltoid muscle strength (measured in abduction) at least 3 out of 548 in the sitting position. Patients with grade 2 or less are not considered for RSA.[49]

The imaging workup should quantify radiographic evidence of grade 3 or 4 fatty infiltration on a computed tomography (CT) scan[35] or magnetic resonance imaging (MRI) study (Figure 9),[50] at the level of the infraglenoid rim according to Greiner et al.[51]

Finally, a preoperative electrodiagnostic study is often useful in the setting of deltoid impairment. This can help determine the etiology and severity of deltoid impairment when a neurological lesion is suspected.

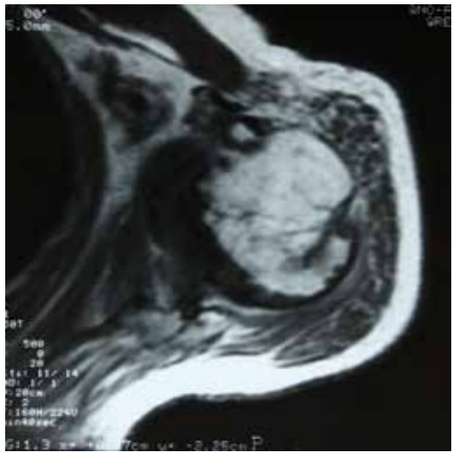


Figure 9
Axial MRI of a right shoulder demonstrates Grade 4 infiltration of the anterior deltoid and grade 3 of the posterior and middle deltoid at the level of the infraglenoid rim

SURGICAL APPROACH AND IMPLANT DESIGN

The surgeon faces three specific challenges with RSA in the setting of preoperative deltoid impairment: respect of the remaining deltoid, protection of the axillary nerve, and avoidance of postoperative instability.

Either a deltopectoral or transdeltoid approach (superior approach)[21,52] may be used and each has its advantages and disadvantages.[53] The situation is fairly different in case of a compromised deltoid, which will be the future motor of the shoulder. The transdeltoid approach has the advantage of obtaining better postoperative stability, in particular, because the subscapularis tendon and the anterior ligament complex are preserved. This approach may be appealing because postoperative instability is a concern in the setting of preoperative deltoid impairment. However, one must consider the potential for additional trauma to the deltoid and consequently we do not recommend this approach for cases with preoperative deltoid impairment. Another alternative approach has been developed to respect the deltoid by performing a deltopectoral approach, without taking the subscapularis down (subscapularis and deltoid sparing approach).[54,55] This effectively combines the deltopectoral and superior approaches and respects the subscapularis, one of the keys for postoperative stability[56] and postoperative function (Figure 10).[57]

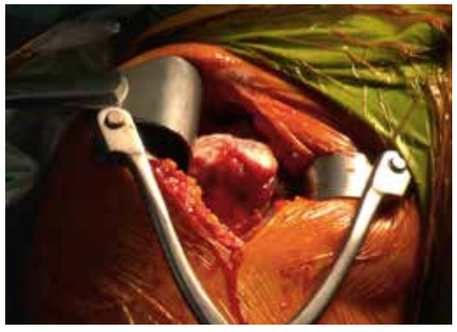


Figure 10
Lateral view from a right shoulder. A deltopectoral approach has been performed. Using a Brown retractor, the superior head then is exposed, allowing to continue through a superior approach and respecting thus the deltoid and the intact subscapularis

Additionally, since the subscapularis is respected, the patients are allowed to move freely and actively the day after the surgery (Figure 11).

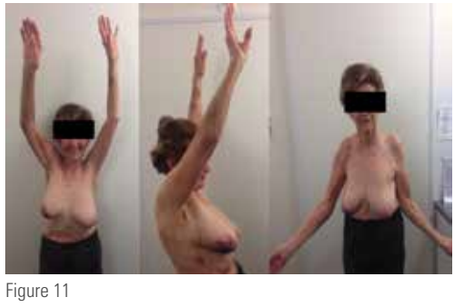


Figure 11
Postoperative motion in a 74 years old patient seven days after RSA implanted through a subscapularis preserving technique. The patient has not been immobilized and encouraged to move immediately freely

In order to improve the lever arm of the impaired deltoid muscle and allow recruitment of more anterior and posterior deltoid fibers, we recommend the use of a medialized glenoid design with a lateralized humeral stem (Figure 12).

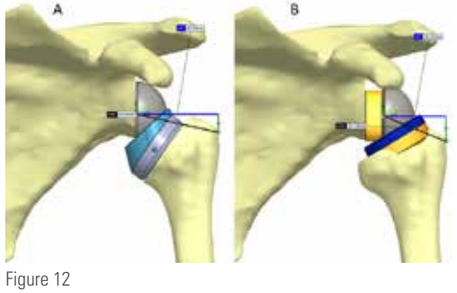


Figure 12
The level arm of the deltoid is highly dependent on prosthetic configuration. A curved 145° stem (A) increased the level of arm of more than 12 mm compared to a standard 155° stem (B).

Furthermore, the principles of restoring humeral length in order to obtain sufficient tension of the remaining deltoid is also employed as it contributes to a lower rate of postoperative dislocation.[58,59] Nevertheless, implantation of a lower (145° or 135°) neck-shaft angle should be used in case of preoperative axillary nerve injury as it theoretically limits deltoid lengthening (Figure 13).

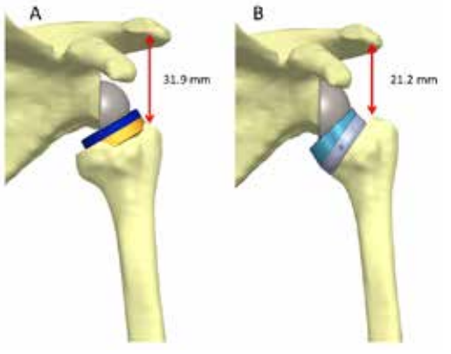


Figure 13
The neck-shaft angle is one of the biggest variabilities between different prosthesis designs. For every 10° decrease the acromiohumeral distance shortens by approximately 3 mm (more than 1 cm in this example). A low neck-shaft angle limits deltoid lengthening and is an option in case a preoperative deltoid impairment

General speaking, lengthening beyond two centimeters compared with preoperative measurement may increase the frequency of postoperative neurological injury.[60] Consequently, this might help prevent a double crush syndrome by decreasing postoperative traction on the plexus.[61] Finally, with a deltopectoral approach the authors believe that if the pectoralis major tendon is partially or completely detached during surgery to improve exposure, it may be important to repair this tendon to aid as an anterior constraint. It has also been demonstrated that the muscle, mainly its clavicular part, could at least partially compensate for the anterior deltoid in forward elevation.[2,62]

DISCUSSION

Few reports have described the outcome of RSA in the setting of deltoid impairment.[27,28,37,44,63] The available data suggest that RSA may indeed be a viable treatment option in the setting of mild to moderate, anterior and middle partial deltoid impairment. It is apparent that not all of the deltoid must be intact for the benefits of a RSA to be realized. Rather, in our opinion it is important to critically analyze the location of the deltoid impairment (Figure 8) and the remaining strength to determine if implantation of a RSA is possible.

It is important to remember that arm elevation is composed of both glenohumeral and scapulothoracic motion. The latter could contribute significantly to postoperative RSA motion in the context of a preoperative deltoid impairment.[64,65] After RSA implantation in the case of deltoid impairment, the deltoid contributes to elevation through the glenohumeral joint. However, scapulothoracic motion also probably increases and contributes substantially to elevation.[64,65]
Even if the rate of complications remains high, few complications can be specifically attributed to the preoperative muscle insufficiency as opposed to complications following RSA in general, particularly revision cases. In fact the complication rate, including the dislocation rate, is comparable to previous series of RSA performed with normal deltoids.[66,67] Thus, it does not seem that preoperative deltoid impairment is related to a higher complication rate or prevalence of dislocation, at least when the impairment is not global. In all studies, the improvement is obtained in postoperative active forward elevation and Constant score.
However, these functional results are, as expected, lower than that described in cases with a normal deltoid.[39,58,59,68,69] It seems that the reverse design allows restoration of elevation above 90°, even with partial deltoid impairment. Not surprisingly, results are less satisfactory when deltoid impairment involves the entire deltoid (type 4). In other words, it seems that the most important factor for postoperative result is the extent of the lesion, and not its cause.[37] Interestingly, patient satisfaction is high in all publications on RSA in the setting of deltoid impairment. However, this is likely related to very poor preoperative function and moderate preoperative expectations of this population.

CONCLUSION

Preoperative deltoid impairment, in certain circumstances, is not an absolute contraindication to RSA. If partial deltoid function remains, especially in posterior part of deltoid, RSA can yield reliable improvements in active forward elevation and functional outcome without excessive risk of postoperative dislocation. However, results are less predictable in cases of global deltoid impairment and this technique is not advised in the absence of deltoid function. RSA is not a panacea in the case of deltoid impairment, but in many cases no other options are available.

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46/ OUTCOME OF REVERSE SHOULDER ARTHROPLASTY IN PATIENTS WITH PARKINSON'S DISEASE: A MATCHED COHORT STUDY

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INTRODUCTION

Parkinson's disease (PD) is a relatively common disorder that affects our geriatric population today, with an annual incidence rate of 20.5 per 100,000.[8,16,22,31] PD patients classically present with a spectrum of clinical symptoms including asymmetric limb resting tremors, bradykinesia, muscle rigidity, flexed posture, and postural instability. The treatment of orthopaedic problems in the PD patient population can be difficult, including fixation failure and prosthetic dislocation.[3,7,14,15,17,20,26,27,29,31]

Several authors have reported successful relief of pain with total knee and hip arthroplasty in patients with PD, but variable functional outcome results due to increased muscle rigidity, flexion contractures, and the severity of the tremor.[5,9,21,22-24,26,28,29] There has been little reported in the literature on the outcomes of shoulder surgery in patients with PD. Authors have reported successful results in relieving pain, but inconsistent results in functional outcome, with early instability being a concern after total shoulder arthroplasty (TSA).[18,19] Because early instability and unsatisfactory results in unconstrained shoulder arthroplasty appear to be higher in this patient population, a reverse shoulder arthroplasty (RSA), which provides inherent constraint, may be a more appropriate treatment option. RSA has been shown to provide safe and effective results in patients with a variety of shoulder pathologic conditions in which there is an unstable fulcrum of the glenohumeral joint.[1,2,4,10,11,12,25,30]

Currently, the use of reverse shoulder arthroplasty (RSA) in Parkinson's patients has not been adequately studied.6 The purpose of this study was to determine if RSA provided similar functional outcomes when compared to a matched cohort of non-Parkinson's patients.

MATERIALS AND METHODS

Study Design

Our prospective database and the hospital medical records were retrospectively searched for patients diagnosed with PD that had undergone RSA. Between February 2001 and May 2011, ten patients with PD were identified that underwent RSA with a minimum of 24 months follow-up. These patients were then matched to a cohort of forty non-Parkinson's patients. Parkinson's disease presents in five different stages, where the more severe stages present with more severe functional limitations. Patients with Stage 1 often have very mild symptoms of tremors and shaking in one limb. Stage 2 presents with bilateral limb symptoms and more walking and balance problems Stage 3 presents with more severe symptoms and may be unable to walk straight or stand. Stage 4 patients are generally unable to complete day-to-day tasks or live on their own. Stage 5 is the last stage as patients are no longer able to care for themselves. Patients undergoing RSA for PD in this series presented with Stage 1 or 2 PD. More advanced stages of PD were not considered candidates for the operation in this series.

All patients included in the study had undergone an RSA using the Reverse Shoulder Prosthesis (DJO Surgical, Austin TX) by the senior author (M.A.F.) after failing non-operative treatment with complaints of moderate to severe shoulder pain, reduced ability to perform daily functions, and evidence of advanced rotator cuff deficiency or failed previous arthroplasty. (Figures 1 and 2)

Figure 1

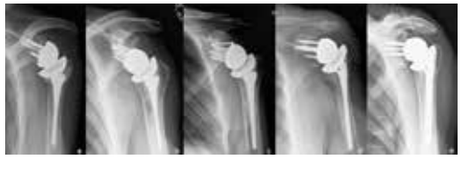

Figure 2

Matching Criteria

Four control patient's without PD were matched to each Parkinson's patient using age, sex, length of follow-up, pre-operative diagnosis, and severity of disease as the match criteria. Pre-operative diagnoses in both cohorts included cuff tear arthropathy (PD=5, non-PD=24), osteoarthritis (PD=1, non-PD=1), failed hemiarthroplasty (PD=2, non-PD=11), and failed total shoulder arthroplasty (PD=2, non-PD=4).

The severity of the disease was determined using data collected during the pre-operative visit and radiographs. The reason for surgery was determined using the patient's operative report, medical record and verified on radiographs. All radiographs for this study were performed at our institution using a standardized protocol including an anteroposterior (AP), scapular Y, Grashey (true AP in the plane of the scapula), and axillary views.

Each Parkinson's patient was further matched to a set of four controls based on the pre-operative radiographs using the following criteria: severity of osteoarthritis according to Hamada,[13] amount of subluxation, and reason for revision, including mode of failure and previous implant (i.e. hemiarthroplasty or total shoulder arthroplasty). The radiographs were then anonymized and presented to a group of four orthopaedic shoulder surgeons for concurrence. Any control that the group felt was not similar enough was removed and a new control was identified by the first author. This process was repeated until a consensus based on the above criteria was met.

Outcomes

Outcome scores were collected and analyzed during the pre-operative visit and final follow up visit for all patients. Patient questionnaires were used to calculate the American Shoulder and Elbow Surgeons (ASES) pain, function and total scores, Visual Analog Scale (VAS) pain and function, and the Simple Shoulder Test (SST) score. Range of motion (ROM) in all four planes was digitally measured using videotaped range of motion by an independent third party. In cases where the pre-operative ROM video was not available, patient indicated ROM from questionnaires was used. (Table 1)

	Controls	Parkinsons	Mann-Whitney U Test
Age (years)	72.7 ± 8.4	75.8 ± 5.5	0.994
Follow-up Time (months)	39.9 ± 18.5	38.4 ± 19.5	0.890
VAS Pain	6.4 ± 2.5	6.3 ± 1.2	0.322
VAS Function	2.3 ± 2.3	2.2 ± 2.4	0.237
ASES Pain	19.2 ± 13.3	18.8 ± 6.2	0.899
ASES Function	18.6 ± 11.7	14.9 ± 15.2	0.721
ASES Total	38.2 ± 17.2	33.7 ± 18.6	0.284
SST	1.6 ± 1.6	1.3 ± 1.1	0.625
FF	55.9 ± 38.1	47.7 ± 34.2	0.778
AB	53. 1 ± 32.3	47.5 ± 26.8	0.763
ER	26.4 ± 32.6	23.3 ± 21.4	0.345
IR	2.3 ± 1.7	1.3 ± 0.9	0.313

Table 1

Source of Funding

DJO Surgical provided research support for this study. DJO Surgical did not have any input to the data collection, interpretation of the data, or writing of the manuscript.

RESULTS

Functional outcomes and range of motion are listed in Tables 2.

	Controls	Parkinsons	Mann-Whitney U Test
VAS Pain	2.7 ± 3.2	3.9 ± 2.8	0.143
VAS Function	6.9 ± 2.7	4.7 ± 2.9	0.042
ASES Pain	36.5 ± 16.2	30.5 ± 14.2	0.143
ASES Function	29.8 ± 13.5	20.5 ± 8.3	0.054
ASES Total	66.4 ± 25.4	51.0 ± 13.2	0.080
FF	127.6 ± 47.5	91.1 ± 66.3	0.109
AB	117.3 ± 50.2	80.0 ± 48.0	0.070
ER	48.2 ± 32.7	16.2 ± 20.3	0.017
IR	4.3 ± 2.5	2.3 ± 2.1	0.028
SST	6.4 ± 2.9	3.8 ± 3.1	0.051

Table 2

Functional Outcome and Pain

Parkinson's patients had statistically significant improvements in SST and ASES total scores, while approaching significance in VAS pain and ASES pain. They did not show statistical improvement in ASES function scores. Control patients had statistically significant improvements in all parameters measured.

Range of Motion

Patients with PD showed statistically significant improvements in forward elevation but no other functional (range of motion) parameter. Control group patients showed statistically significant improvements in all planes of motion (forward elevation $p<0.0001$, abduction $p<0.0001$, external rotation $p = 00.018$, internal rotation $p = 0.001$).

Complications

Complications occurred in 4 out of 10 (40%) in the Parkinson's group and 6 out of 40 (15%) in the control group. Two patients with Parkinson's sustained a postoperative acromial fracture, one had glenoid baseplate failure, and one developed post-operative instability. The patient with glenoid baseplate failure was a 79-year-old female with advanced disease although still ambulatory with assistance. She was noted intra-operatively to have significant deltoid spasticity. She was treated post-operatively with deltoid botulinum toxin injections and elected for non-operative treatment of her glenoid component failure. One patient had two episodes of post-operative instability and required one revision surgery for his initial episode. Both patients with acromial fractures were treated non-operatively. In the control group, there were four acromial

fractures, one failed baseplate due to a broken central screw and one case of instability with an associated dislocated poly socket. All four acromial fractures were treated non-operatively. The baseplate failure and dislocated poly component were both revised. The reoperation rate was 10% in the PD group and 5% in the control group.

DISCUSSION

Parkinson's disease presents a challenge in the surgical treatment of orthopaedic conditions, particularly in the use of shoulder arthroplasty. Koch et al. reported on 15 patients with PD who underwent 16 unconstrained shoulder arthroplasty.[18] While the patients had significant pain relief, functional outcomes were poor and complications were more frequent, especially in patients older than 65 years.

Likewise, Kryzak et al. reported on 43 unconstrained shoulder arthroplasties in patients with PD.[19] TSA resulted in significant long-term pain relief. However, eight of 43 required revision shoulder arthroplasty, while 20 (47%) achieved unsatisfactory functional results.

Because unsatisfactory functional results and early instability are a concern with unconstrained shoulder arthroplasty in patients with PD, the use of RSA, which is inherently more stable, may provide a better option for these difficult patients. However, the use of RSA in this patient population has been underreported.

Dunn et al reported on 3 cases of Grammont-style RSA in patients with PD in which pain relief was reliably achieved, but functional outcomes were poor.6 However, none of the patients presented with glenohumeral arthritis or rotator cuff arthropathy. Two cases were revision arthroplasty cases (failed hemiarthroplasty and deep infection) and one was a RSA for proximal humerus fracture. All patients developed significant scapular notching and subsequent poor clinical function.

In the current study, PD patients undergoing RSA achieved improvements in pain scores and clinical improvements in forward elevation and abduction, but not internal or external rotation. Only postoperative forward elevation reached statistical significance compared to their preoperative state. There was no difference between Parkinson's and non-Parkinson's patients with regards to postoperative forward elevation and abduction, but there was a significant difference in internal and external rotation. There was a significant difference in functional outcome scores between the two groups, with the control group performing better. Also, there was a much higher complication and reoperation rate in the PD patient group.

There are limitations to the current study. First, our experimental group is small with only 10 patients with PD undergoing RSA. However, this is the largest group of Parkinson's patients undergoing RSA reported in the literature and provides preliminary evidence to guide surgeons in counseling patients with PD on the outcomes in RSA. Additionally, the study is strengthened by a rigorous case-control match in order to compare these patients to a similar group of non-Parkinson's patients. Second, we did not evaluate the stage of Parkinson's disease for each patient. It is likely that the worse the patient's disease state the worse their clinical outcome would be. It has been recommended that RSA should only be considered in patients with a mild stage of the disease, as more severe cases likely would result in higher complication rates and worse functional outcomes due to their increased muscle rigidity, tremors, unsteady gait, and dementia.

All shoulder arthroplasties performed at our institution are performed by a high volume shoulder arthroplasty surgeon. Our control group in this series has demonstrated good outcomes post-operatively, with statistically significant improvements in both pain and function. Outside of surgical technique, we believe the medical management of the disease can play a significant role in these patients overall outcomes. For this reason we recommend a multidisciplinary approach to the Parkinson's patient requiring shoulder replacement surgery. Patients with more advanced disease preoperatively should not be considered candidates for surgery. Close collaboration with neurology and optimization of the patient's disease from a medical standpoint can optimize the post-operative course. We now routinely consult neurology both pre and post-operatively in these patients. The role of intra-operative or post-operative botulinum toxin injections is still unclear.

CONCLUSION

Parkinson's patients achieve similar reductions in pain but inferior clinical function following RSA compared to similar patients without Parkinson's. Improvement in range of motion is less predictable and complication rates are significantly higher in patients with Parkinson's. It is important to counsel patients with PD and carefully educate them on their risks and potential outcomes before selecting RSA as the treatment for their shoulder pathology.

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LEGENDS FOR FIGURES

Figure 1 Preoperative radiographs of Parkinson's patient (1A) and the four matched control patients (1B-E).

Figure 2 Postoperative radiographs of Parkinson's patient (2A) and the four matched control patients (2B-E).

Table 1 Preoperative and Demographic Comparisons for Matching; VAS, Visual Analog Scale; ASES, American Shoulder and Elbow Society; SST, Simple Shoulder Test; FF, forward flexion; AB, abduction; ER, external rotation; IR, internal rotation

Table 2 Preoperative and Postoperative Functional Outcome Comparisons For Each Group ; VAS, Visual Analog Scale; ASES, American Shoulder and Elbow Society; SST, Simple Shoulder Test; FF, forward flexion; AB, abduction; ER, external rotation; IR, internal rotation

Table 3 Postoperative Functional Outcome Comparisons Between Groups; VAS, Visual Analog Scale; ASES, American Shoulder and Elbow Society; SST, Simple Shoulder Test; FF, forward flexion; AB, abduction; ER, external rotation; IR, internal rotation.

47/ ARE THE CLINICAL OUTCOMES OF THE REVERSE TOTAL SHOULDER ARTHROPLASTY WITH AN EPISCOPO PROCEDURE MAINTAINED OVER TIME?

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INTRODUCTION

Reverse shoulder arthroplasty (RSA) by passing through years of continuous developments and renovations since its introduction in 1987, has become a reliable solution to restore overhead activities of daily living in a pseudo-paralyzed shoulder with massive irreparable rotator cuff tear.[1-3]. More lateralized designs have been introduced and could help obtain greater range of motion especially in axial rotation.[4] However, several studies have shown that RSA cannot restore active shoulder external rotation in the absence of both infraspinatus and teres minor in massive posterosuperior cuff tear.[3, 5, 6] Therefore, a preoperative external rotation lag sign and the inability to perform active external rotation will remain and might even be exaggerated following RSA in this subgroup of patients.

Gerber et al. and Boileau et al. were first to describe the technique of latissimus dorsi tendon transfer combined with RSA to restore both shoulder elevation and external rotation and they reported promising short-term results.[7, 8]. To our knowledge, no studies have focused on the long-term durability of this technique. The purpose of our study was to analyze and report long-
term functional results and complications of RSA combined with a modified L'Episcopo technique.

We hypothesized that the gain in shoulder external rotaion and its benefits in activites of daily living would be maintained through time.

MATERIALS AND METHODS

All patients who underwent RSA combined with a latissimus dorsi and teres major transfer (modified L'Episcopo technique) in our institution between 2006 and 2015 with a least 2 years of follow-up were included.

The indications for this procedure included: (i) painful pseudoparalytic shoulder due to massive postero-superior cuff tear; (ii) loss of active shoulder external rotaion(ER) and elevation and a positive external rotation lag sign; (iii) a functional deltoid; (iv) gleno-humeral arthritis (Hamada > 3); (v) fatty infiltration of the infraspinatus and of the teres minor ≥3 in the Goutallier classification[10].

Deltoid palsy, a history of infection or severe glenoid bone deficiency were a contraindication to perform a RSA. Patients with more than 0° of active ER with the arm at the side were not eligible for a tendon transfer.

Pre- and postoperative clinical evaluation was performed and included: active and passive shoulder range of motion in forward flexion, abduction, external rotation with the arm at the side (ER1) and at 90° of abduction(ER2) and in internal rotation, and the following functional scores : Constant-Murley, Subjective Shoulder Value (SSV), visual analog scale (VAS) and the Simple Shoulder Test (SST).

Three patients had a history of surgical fixation of proximal humerus fracture, 5 patients had had prior rotator cuff repair and 2 patients had had a previous acromioplasty. In 21 shoulders there was no history of previous intervention. Preoperative radiographs and MRIs were performed and the severity of cuff tear arthropathy was assessed according to the Hamada and Fukuda classification[11]: 21 patients were graded 4A, 9 were 4B and 1 case was graded 5.

Postoperative visits were done at the 1st week,1st, 3rd, 6th month and once a year thereafter. Postoperative AP and lateral radiographs were assessed for the position of the implant and radiolucent lines.

Surgical technique

All operations were performed by the senior author(PV) in the beach chair position under general anesthesia in combination with an interscalene block. The surgical technique was similar to the technique previously described by Boughebri et al. except for the fixation method of transferred tendons [12]. A single extended delto-pectoral approach was performed from clavicle to the inferior border of the pectoralis major (PM) tendon. The latissimus dorsi (LD) tendon was found below the inferior border of subscapularis attachment. Partial tenotomy of the PM tendon performed to gain access to the LD tendon however, in the most recent cases a double bent blunt Hohman retractor was placed behind the PM tendon, to expose the LD tendon without the need for a tenotomy. Both LD and teres major (TM) tendons were detached from the bone subperiosteally and were completely from one another.

A lateralized RSA (Arrow, FH Orthopedics, Mulhouse, France) was used in all cases.

Both tendons were fixed separately to the posterolateral part of the proximal humerus by two non-absorbable braided trans-osseous sutures.

Post-operative protocol

Patients were placed in a custom-made shoulder spica brace in 20° of abduction and in neutral rotation for 6 weeks. The patient then began active assisted range of motion exercises in every direction except external rotation for 4 weeks (from weeks 8-12), then full range of motion and gentle strengthening after that. Patients were allowed to return to unrestricted activities after 6 months.

Statistical analysis

In addition to descriptive statistics, univariate analysis was used to compare the differences between preoperative and postoperative data using the 2-sample 2 test (or Fisher exact test) for categoric variables, or the Student t test of unequal variance for continuous and categoric variables. All analyses were performed using JMP 8 software (SAS Institute Inc, Cary, NC, USA). A P value of <0.05 was considered statistically significant.

RESULTS

A total of 30 patients (31 shoulders, 14 men and 16 women) with an average age of 69.7 years (range; 52-83 years) were included in the study.

Patients were divided in two groups according to the length of follow-up (between 2 and 5 years vs more than 5 years). At final follow-up we had 13 shoulders in Group 1 (range; 25-58 months) and 18 shoulders in Group 2 (range; 63-141 months). The results are detailed in Table 1. Comparing pre and post-operative examinations, both groups showed significant improvement in external rotation, abduction and forward flexion and in the Constant, SST, SSV and VAS score. There was no significant decrease in the functional level of internal rotation.

Comparing the functional results between the two groups, no significant difference was found. These results are detailed in Table 2.

At the last follow-up 29 patients were very satisfied or satisfied and 2 patients were not satisfied with the results of surgery.

Complications

There was a total of 5 major complications which required revision surgery : 4 cases of infection and one case of instability with inferior subluxation.

DISCUSSION

Gerber et. al. and Boileau et al. first described RSA combined with Latissimus dorsi tendon transfer to restore active elevation and external rotation with promising results.[8] The following years, several groups reported improvement in active shoulder external rotation following LD with or without TM tendon transfer combined with RSA, with short-term follow-ups.[12-15]

In this study we wanted to evaluate the durability of tendon transfer function as an active external rotator after 5 years of follow-up.

In all cases we transferred both LD and TM muscles through a single deltopectoral approach. Both muscles were separated from one another and transferred separately. The excursion of the LD is greater than that of the TM and can be fixed more proximally without extensive release. By separating the insertion site of the two tendons we possibly decrease the final tension on the TM and theoretically decrease the risk of axillary nerve compression.

The present study shows that the early gain in shoulder range of motion, especially in external rotation after the combination of a L'Episcopo procedure with a RSA does not appear to deteriorate in the long term. In addition, the Constant-Murley and SSV scores showed constant improvement through the time.

Forward elevation in both groups was more than what was generally reported following RSA alone but was comparable with what has been reported in other studies of RSA in combination with a L'Episcopo transfer and this could be due to the fact the transferred LD can help improving forward elevation as discussed by Puskas et al. [16].

Boileau et al. reported a loss of active shoulder internal rotation from L1 to S3 following RSA in combination with a L'Episcopo procedure.[17] However, no such loss in internal rotation was observed in this study at short- or long-term follow-up. One hypothesis for this observation could be the difference in biomechanics of a more lateralized RSA which is thought to give better results in internal rotation.

There were 4 cases (12.9%) of infection in this series which is more than the average post-operative infection rates reported after RSA. By combining RSA with L'Episcopo tendon transfer, we prolong the overall surgery time and blood loss which can increase the risk of peri-operative infection.

Our study has several limitations as it is a retrospective study with a limited number of patients.

CONCLUSION

For patients with combined loss of active elevation and loss of active external rotation due to massive rotator cuff tear, the combination of a RSA with LD+TM tendon transfer can result in significant improvement in active shoulder elevation and external rotation. This gain in active range of motion persists through time. Larger series including different prosthetic designs will help to discuss more precisely the biomechanical aspects of this procedure.

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Table 1 Comparison between preoperative and postoperative functional evaluations following reverse shoulder arthroplasty combined with modified l'Episcopo tendon transfer

Variable	Group 2-5y (13 shoulders)			Group >5 (18 shoulders)			All patients (31 shoulders)		
	preop	postop		preop	postop		preop	postop	
	Mean ± SD	Mean ± SD	P	Mean ± SD	Mean ± SD	P	Mean ± SD	Mean ± SD	P
Forward elevation°	80 ± 31	147.7 ± 26.8	.000	64.4 ± 33.8	118.9 ± 37.6	.000	71 ± 33	131 ± 36	,000
Abduction°	68.5 ± 22.3	120 ± 16.3	.000	57.2 ± 26.3	105 ± 31.3	.000	61.9 ± 25	111.3 ± 26.8	,000
ER1°	-14.6 ± 19.8	15.4 ± 15.6	.000	-11.1 ± 21.4	20.6 ± 11.1	.000	-12.6 ± 20.5	18.4 ± 13.2	,000
ER2°	-3.9 ± 15	42.7 ± 22.8	.000	-11.1 ± 16.8	35 ± 25.3	.000	-8 ± 16.2	38.2 ± 24.2	,000
IR II(Grade)	5 ± 2	5 ± 2	.86	4.9 ± 2.6	5.3 ± 2	.45	5 ± 2	5 ± 2	,693
Constant-Murley score:									
Total(x/100)	26.6 ± 7.3	63.2 ± 8	.000	25 ± 11.1	56.9 ± 11.5	.000	25.7 ± 9.6	59.6 ± 10.5	,000
Adjusted[a](%)	36.8 ± 11.6	86.3 ± 12.4	.000	39.3 ± 13.3	77.3 ± 15.9	.000	38.2 ± 12.5	81 ± 15	,000
SSV(%)	30.8 ± 16	75 ± 14.3	.000	37.2 ± 15.6	68.9 ± 17.5	.000	34.5 ± 15.9	71.5 ± 16.2	,000
SST(x/12)	3 ± 1.8	7.8 ± 2.5	.000	2.2 ± 1.3	7.8 ± 1.8	.000	2.5 ± 1.6	7.8 ± 2.1	,000
VAS(x/10)	5.9 ± 2.5	1 ± 1	.000	6.1 ± 2.6	0.94 ± 0.87	.000	6 ± 2.5	1 ± 0.95	,000

Table 1
Group 2-5y, patients with 2-5 years follow-up; Group >5y, patients with more than 5 years follow-up; ER1, Shoulder external rotation arm beside body; ER2, Shoulder external rotation arm abducted 90∞; SSV, subjective shoulder score; SST, simple shoulder test
Grade of active internal rotation according to Constant-Murley score
Age and sex adjusted Constant-Murley score

Table 2 Comparison between postoperative functional evaluations following reverse shoulder arthroplasty combined with modified l'Episcopo tendon transfer according to the length of follow-up

Variable	postop		
	Group 2-5y	Group >5y	
	Mean ± SD	Mean ± SD	P[b]
Forward elevation°	147.7 ± 26.8	118.9 ± 37.6	.019
Abduction°	120 ± 16.3	105 ± 31.3	.117
ER1°	15.4 ± 15.6	20.6 ± 11.1	.470
ER2°	42.7 ± 22.8	35 ± 25.3	.349
IR II (Grade)	5 ± 2	5.3 ± 2.3	.548
Constant-Murley score: Total(x/100)	63.2 ± 8	56.9 ± 11.5	.100
Adjusted(%)	86.3 ± 12.4	77.3 ± 15.9	.096
SSV(%)	75 ± 14.3	68.9 ± 17.5	.072
SST(x/12)	7.8 ± 2.5	7.8 ± 1.8	.806
VAS(x/10)	1 ± 1	0.94 ± 0.87	.948

Table 2
ER1, Shoulder external rotation arm beside body; ER2, Shoulder external rotation arm abducted 90∞; SSV, subjective shoulder score; SST, simple shoulder test
Grade of active internal rotation according to Constant-Murley score

48/ IS SMALL GLENOID COMPONENT OF RSA NECESSARY IN KOREAN POPULATION?

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INTRODUCTION

The reverse total shoulder arthroplasty (RSA) was introduced into Korea in 2007. Since then, reverse total shoulder arthroplasty (RSA) has been increased in Korea. Over the last 5 years, the number of RSA increased from 977 to 2,972 cases in Korea and the proportion of RSA in shoulder arthroplasty increased from 60.4% to 83.8%. (table1)

Year	Shoulder Arthroplasty (cases)	RSA (cases)	Ratio of RAS (%)
2012	1,617	977	60.4
2013	1,892	1,326	70.1
2014	2,308	1,781	77.2
2015	2,727	2,255	82.7
2016	3,548	2,972	83.8
Sum	12,092	9,311	77.0

Table 1
Shoulder Arthroplasty between 2012 and 2016 years in Korea

As the number of RSA increase, we were concerned that the prosthetic component might be too large or create an increased complication rate in an Asian population because that shoulder prosthesis was designed in Europe or America. Kim YS et al.6 demonstrated that the size of the female glenoid was sometimes smaller than the baseplate in a Korean population, and claimed that manufacture of a new prosthesis size suitable for Koreans should be undertaken. When a large baseplate is positioned on a small glenoid, the risk of baseplate instability is likely to increase. So advances in implant design have improved the clinical outcomes of shoulder arthroplasty.

Glenoid Size and Depth of Vault in Asian including Korean Population

Several studies have evaluated glenoid morphology in Asian, black and white populations. In a study of mostly Caucasians, Iannotti et al.5 measured the glenoid of cadavers and living patients using a caliper or magnetic resonance imaging and found a mean glenoid height of 39±3.5 mm and width of 29±3.2 mm. And Churchill et al.2 reported that mean glenoid height of men was 37.5 mm (range, 30.4 - 42.6mm) and women was 32.6 mm (range, 29.4 – 37.0 mm) in black and white population. In contrast, Matsumura et al.7 analyzed 160 healthy Japanese shoulders using CT scans and reported an average glenoid height of 31.5±2.8 mm and glenoid width of 23.1±2.4 mm. And Phonphok and Kulkamthorn8 in a study of Thai people reported a mean glenoid height and width of 32.3±3.2 mm and 24.4±3.2 mm, respectively. We also measured glenoid size on preoperative CT scans of 32 patients who underwent RSA for cuff tear arthropathy in the our hospital from 2012 to 2017 year. The height of average glenoid was 33.5±2.7 mm in male and 29.7±3.8 mm in female, and the width of glenoid was 26.0±2.2 mm in male and 21.5±2.5 mm in female. In comparison with Europeans or Americans, the glenoid size of Korean is generally smaller according to these studies.2

When we conduct an arthropasty surgery, not only the height and width of glenoid, but the glenoid vault shape and size are important factors for secure fixation of glenoid component. In previous studies, glenoid vault shape and size were also analayzed. Michael K. Codsi et al.3 evaluated variations in glenoid vault shape and size from 3-dimensional (3D) computed tomography (CT) reconstructions of 61 cadaveric scapulae. In this study, 5 triangles model was used to defined the simple geometric model of the glenoid vault. (figure 1.) and dimensions for each of the triangles was evaluated. (Table 2) As shown in fig. 1, triangle 1 showed the deepest dimension and triangle 2 & 3 showed the shallowest dimension within the glenoid vault.

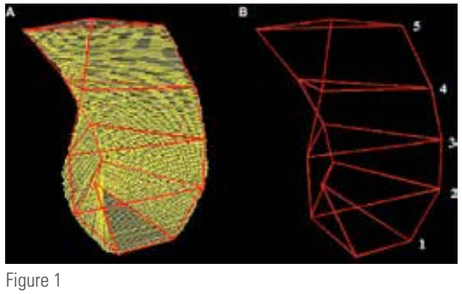

Figure 1
Simplified geometrical approximation of the initial triangular vault model

Triangle	Width (mm)	Depth (mm)	Area (mm^2)
1	10.01	28.50	140.81
2	22.27	19.75	221.69
3	22.26	18.00	201.97
4	17.51	20.75	206.32
5	10.51	22.50	121.63

Table 2
Dimension for each of the triangles

We have studied not only glenoid size but also morphology of glenoid vault using preoperative computed tomography (CT) scans of 32 patients who underwent RSA. The patients with severe arthritis change, previous fracture and dislocation, and retroversion of glenoid were excluded. In our study, the maximum glenoid vault depth was 29.5 mm and located between glenoid center and 4mm posteroinferior. And we also found that inferior vault was deeper than superior vault. (Figure 2)

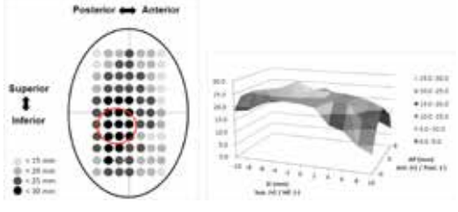

Figure 2
Mean glenoid depth. The deepest area is located between glenoid center and 4mm posterior, inferior area

Cage Placement in Small Glenoid

We performed the study to see the location of the cage in relation with vault and vault penetration or cortex penetration of the cage. A total of 31 patients who underwent reverse total shoulder arthroplasty (Exactech, Equinoxe) at 3 hospitals (Catholic medical center, C.M.C = 9, Seoul National University, S.N.U = 9, Samsung medical center, S.M.C = 13) were included. We inserted central peg screw more superiorly in small glenoid. (Figure 3)

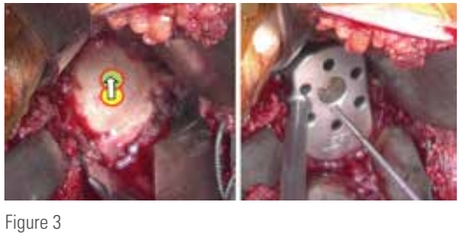

Figure 3
Central peg screw inserted at superior area of glenoid center

The computed tomography scans were performed at 6 months postoperatively, when the cage was located in the cortical bone, It was defined as appropriate fixation. If the cage protruded out of the cortical bone in the axial and coronal view, it was called inappropriate fixation. The Center-Prosthesis distance was measured using computed tomography scans. We measured the Inferior to Center distance (A), the Inferior to Prosthesis distance (B) and obtained the Center - Prosthesis distance (C) by the following formula. (Figure 4, 5)

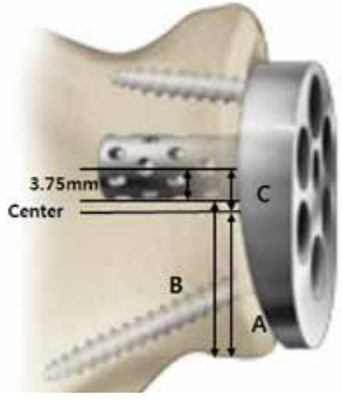

Figure 4
C(center prosthesis distance) = B(inferior prosthesis distance) + 3.75 – A(inferior center distance)

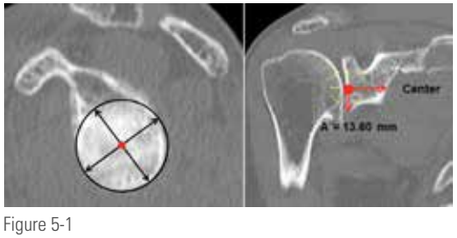

Figure 5-1
A (Inferior center distance) = 13.60 mm

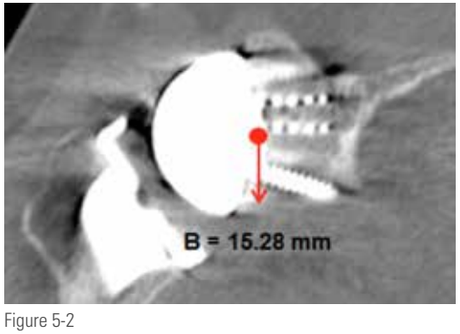

Figure 5-2
B (Inferior prosthesis distance) = 15.28 mm
C (center prosthesis distance) = (B + 3.75 mm) – A = (15.28 mm + 3.75 mm) – 13.60 mm = 5.43 mm

In this study, the inappropriate fixation with cortical perforation was 10 (32.3%) out of 31 cases. And location of cage exposure was superior portion of glenoid (Table 5, 6 and figure 6). There was statistically significant difference in the Center-Prosthesis distance between appropriate fixation group and inappropriate fixation group as well.

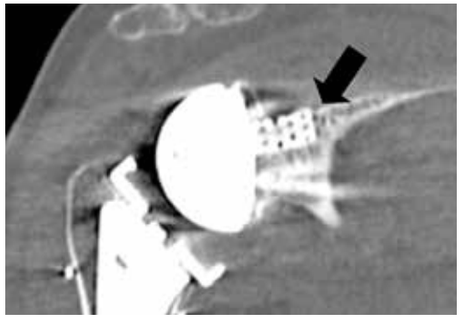

Figure 6
The typical examplel of inappropriate fixation of cage

	Total, N	Inappropriate fixation, N (%)	Location of cage exposure
C.M.C	9	3 (33%)	Superior part
S.N.U	9	3 (33%)	Superior part
S.M.C	13	4 (31%)	Superior posterior

Table 5
Inappropriate fixation of Cage in RSA

	Center–Prosthesis distance (mm)			
	Mean Center–prosthesis distance	Appropriate fixation group	Inappropriate fixation group	*P*
C.M.C	5.19	4.72	6.91	0.024
S.N.U	5.00	4.37	6.30	
S.M.C	5.21	3.15	7.27	

Table 6
Center – Prosthesis distance (mm) of appropriate and inappropriate groups

CONCLUSION

There is a concern that the commonly used RSA implants that were designed and developed in Western countries may not be of appropriate fit for Asian people's shoulders. In our study, we could find that standard baseplate was protruded superiorly when we applied it in small glenoid. There was also significant difference in center-prosthesis distance between appropriate fixation group and inappropriate fixation group. It means that the size of glenoid is sometimes smaller than the standard base plate in Korean population.
Harman, M. et al.4 reported that in small glenoid, the standard glenoid implant (29 mm) is larger than glenoid bone stock, which results in an insufficient bone implant contact and screw fixation, especially of anterior and posterior holes of the baseplate. Initial rigid fixation of the glenoid baseplate is dependent on placement of the screws and glenoid bone stock4. Insecure initial fixation due to inadequate bony support to the baseplate and screw fixation is likely to result in glenoid loosening and decreased longevity of the RSA.
In a biomechanical study using Korean female cadavers of short stature (< 160 cm), Chae et al.1 observed that the micromotions of 29 mm baseplate were higher than those with 25 mm baseplates although no statistically difference was evident. They suggested that their specimens did not have sufficient glenoid bone stock to securely fix a 29 mm baseplate and that this inappropriate size match could result in early glenoid loosening.

In conclusion, using a smaller diameter baseplate for small glenoid would serve to improve initial fixation of glenoid component in terms of contact surface area and bony support to the baseplate. A smaller diameter baseplate of RSA is necessary, especially in small, female, and Korean patients. (Figure 7.)

Figure 7
Small glenoid base plate features

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49/ COMPLICATIONS OF REVERSE TOTAL SHOULDER ARTHROPLASTY - HOW TO MANAGE FRACTURES OF THE SCAPULA?

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ABSTRACT

Total (TSA) or reverse total shoulder arthroplasty (RSA) for severe glenoid defects is a well-known challenge. With an increasing number of performed arthroplasties, the treating surgeon deals not only with primary cases (degenerative, congenital, rheumatoid, post-traumatic), but also with complex revision procedures. Featuring 4 cases we present the treatment of complex situations including revision arthroplasty and severe glenoid bone deficiency. We explain planification, reasoning and principles of using custom made patient specific implants which can be used to solve these situations.

INTRODUCTION

Severe glenoid bone destruction can be treated using different techniques, including hemiarthroplasty, glenoid reconstruction with bone grafts, eccentric reaming, TSAs with wedged or augmented baseplates for the glenoid component, with lateralized or inferiorized glenosphere models, etc. Reverse total shoulder arthroplasty (RSA) plays an important role in shoulder function reconstruction, having the potential to deliver good postoperative outcomes even in complex situations[1–4]. In most of the cases with glenoid deformations, an augmented glenoid/glenosphere baseplate should suffice, likewise autologous grafting. However, recently published studies demonstrate a disquieting number of complications and failures after complex glenoid defects treated with standard RSAs[2, 5–7].

Recent technological advancements showed superior intra- and postoperative results when using preoperative 3D surgery planning tools and patient specific guides for the central glenoid pin[8–10]. Nevertheless, planning the surgical treatment for complex shoulder deformities in case of massive glenoid defects pushes the new technology already to its limits when reaming and grafting seems insufficient. However, additive manufacturing - also known as rapid prototyping or three-dimensional (3D) planning and printing - is gradually gaining acceptance in the surgical sector[9, 11–18]. Being already known and used for severe acetabular defects in hip surgery, the introduction of 3D custom made patient specific implants into the field of shoulder arthroplasty allowed us to reconstruct the glenoid in cases where bone grafts were not sufficient or have already failed.

We have gained some experience with custom made patient specific implants and present the process of planification and surgical steps in 4 cases.

Principles of using patient specific implants in primary total shoulder arthroplasty or revision arthroplasty

Computer-aided design and computer-aided manufacturing, also known as rapid prototyping and 3D printing, is currently being used as a salvage approach for joint restoration in complex cases. This new exciting technological platform plays a role since early 1980s across diverse sectors as art, architecture, food production, automobile or aero spatial industry, but it is only in recent years that its potential in medicine has begun to receive attention. It has been successfully used in knee or hip arthroplasty and it offers an unlimited array of possible applications in reconstructive surgery. The new printing technology opens up the possibility of creating custom made implants with specific structural features out of different metals, PEEK, autologous skeletal stem cells or new materials with mechanical properties close to the bone.

Opposite to the traditionally made orthopaedic implant, the newly designed implant has fewer geometric limitations. There is no need of creating a mould or pressing titanium sheets because the implants are built (printed) in layers from powdered metal after creating a 3D model based on the patients' computer tomography (CT) data. The virtual design of the implant is subjected to Finite Element Analysis in order to test and simulate the forces acting on the bone-implant interface, anchorage options and to establish the final joint range of motion, thus predicting the behaviour of the implant in its environment. Once the surgeon validates the model, technical standards are set out. Implants, implant-demos, anatomic

models and surgical guides are printed. Before delivery to the hospital, the definitive implant is optically scanned for comparison with the 3D design file, packed and sterilized. Additively manufactured implants are developed to improve the surgical process by decreasing the surgical steps and time as well as revision numbers. Moreover, the surgeon has the possibility of simulating and preparing the surgery long-time before the real surgery. The technological process of creating PSIs is described in Fig 1.

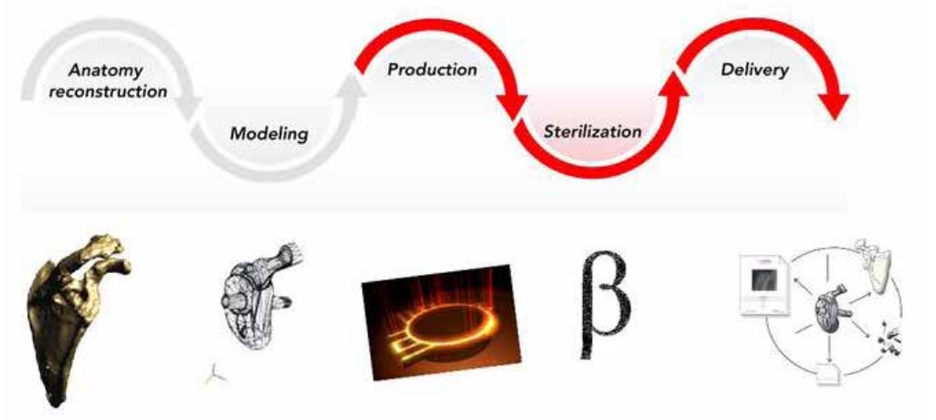

Figure 1
Anatomy Reconstruction: during this phase, the engineers are receiving the shoulder CT scan and create a 3D CAD Model based on the most reliable bone regions. Modeling: The bone stock is evaluated, the defect is quantified and a compatible augmentation is designed in order to achieve the best fixation and final range of motion. Following the first design proposal, a discussion with the surgeon is conducted in order to confirm the PSI design and to agree on surgical technique. Production: 3D Printing Electron Beam Melting technology overcomes all limitations related to conventional manufacturing processes (machining, milling). Quality control, compatibility and tolerance check are mandatory. Sterilization is performed in compliance with the legal requirements. Delivery: the definitive PSI is delivered to the hospital with plastic anatomical models, plastic phantom, PSI, resection guides, cutting jigs and user manual. (We acknowledge the help of the Promade Business Unit Manager, Mr. F. Segatti, Limacorporate S.p.A, for delivering this figure and explanations)

However, no innovation comes without challenges. Surgery should remain simple, efficient and exact, and if possible, cheap. PSIs are custom made, complex in shape and not so fast available as standard implants. Since there is no high volume production rate and the automatization of the manufacturing process is low, the final implant price may seem extremely expensive. This is also due to the workflow steps involving extensive CT analysis and data conversion into manufacturing inputs, CAD specialists, overhead monitoring, regulations and not least niche expertise. Despite high implant price tag, using PSIs may be cost effective because it potentially provides better patient outcomes, brings lower maintenance for instruments, implants and their logistic necessities, avoids multiple or revision surgeries by generally reducing costs for the healthcare system.

CLINICAL CASES

1st Case: Primary RSA for a massive supero-central glenoid erosion in a rheumatoid patient.

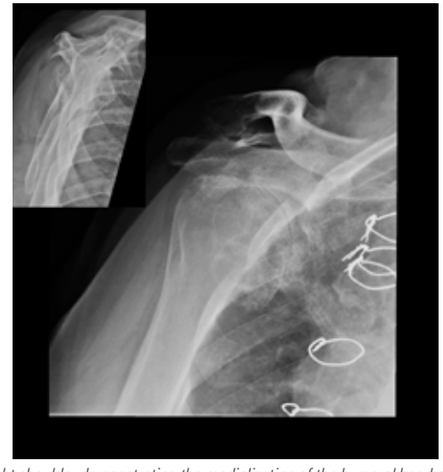

Fig 2. AP and Y-Profile X-Ray of a right shoulder demonstrating the medialization of the humeral head due to glenoid erosion.

Fig 3. Preoperative situation, reconstruction based on the CT data

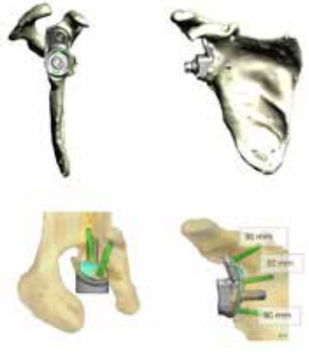

Fig 4. 3D simulation of the patient specific implant with the reconstructed centre of rotation and the pre-calculated exactly defined position of the central peg and 3 anchoring screws

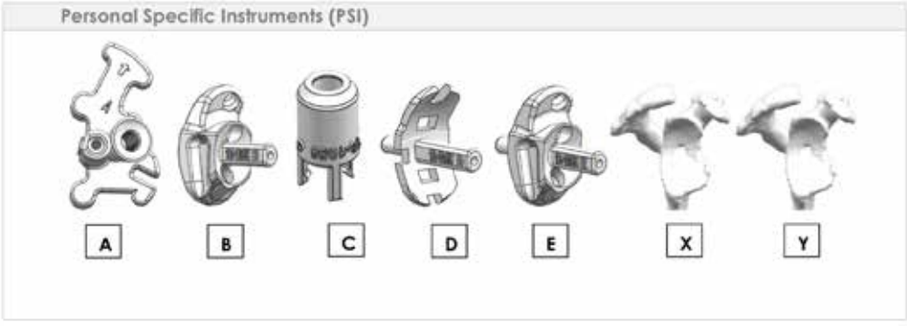

Fig 5. Specific instruments to find and prepare the exact location and direction of the central drill hole for the patient specific peg

Fig 6. Postoperative X-Ray and clinical result at 4 weeks. It is of course possible to achieve a similar good outcome using a big structural graft. However, a "standard" reconstruction with a bone graft and a "normal" baseplate may insufficiently lateralise the centre of rotation or even compromise the clinical result (graft resorption, baseplate anchorage problems, etc.). Bone grafting is intraoperatively much more complex and challenging to the surgeon than using the precisely predefined custom-made implant.

2nd Case: Eccentric postero-superior glenoid erosion with massive glenoid deformation in a 85 years old lady.

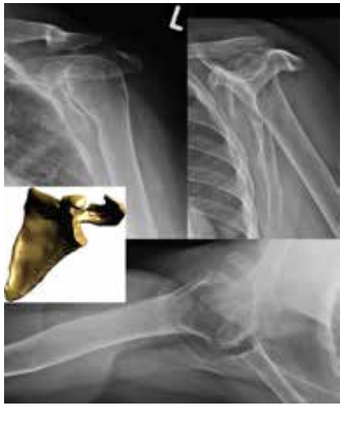

Fig 7. Preoperative situation: massive eccentric glenoid erosion and deformation of the humeral head. Observe the typical notching at the level of the proximal humeral diaphysis.

The standard treatment with autologous bone grafting would have been maybe possible, but definitely at its limit, given the low quality and quantity of the humeral head bone stock (that can be sometimes used as an autograft), age and rheumatoid disease; graft resorption and glenosphere loosening are the most common complications. Iliac crest bone may offer a more reliable bone quality but it causes donor site morbidity and in contrast to the specific implant which can be adjusted extremely precise to the patient's individual defect ("surgery before the surgery"), it will always require a complex and time consuming intraoperative adjustment of the graft/glenoid interface.

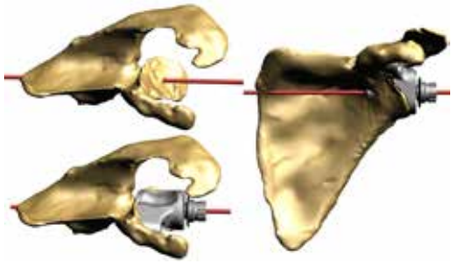

Fig 8. 3D planning of a patient specific implant

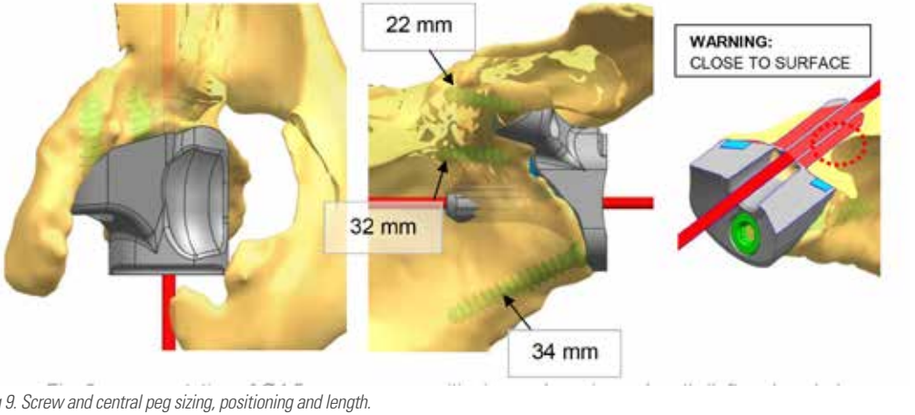

Fig 9. Screw and central peg sizing, positioning and length.

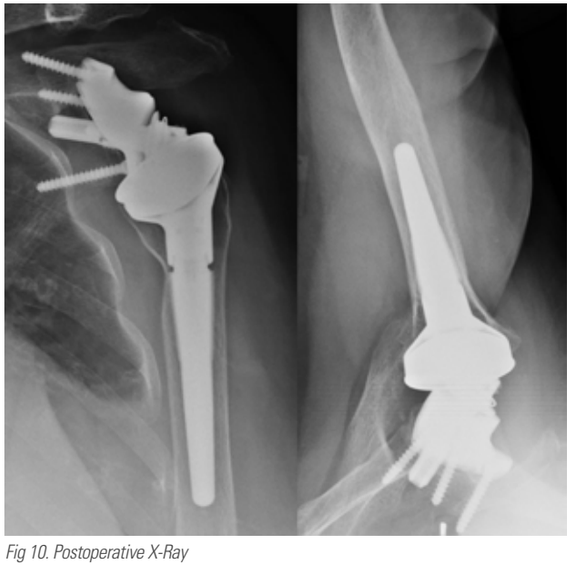

Fig 10. Postoperative X-Ray

3rd Case: Revision of an unstable RSA

History: 63 years old female patient had an osteosynthesis failure with humeral head necrosis after a proximal humerus fracture. Having a complete loss of all parts of the rotator cuff and proximal humerus, she received a reverse total shoulder arthroplasty alio loco that was revised 3 times for recurrent RSA dislocations. The patient was in a chronic anterosuperior dislocation over the last 6 months.

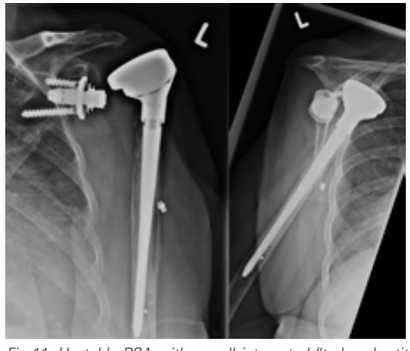

Fig 11. Unstable RSA with a well integrated "trabecular titanium" (TT) long peg base plate.

The therapeutic strategy was to increase the soft tissue tensioning not by simply distalizing the humerus – by increasing the size of humeral liners - but by lateralizing the position of the glenosphere. The problem here was that the base plate was already well integrated with a TT implant and removing it, bone grafting and reinserting another base plate would have been unpredictable. Therefore, a custom made implant which allowed lateralization of the glenosphere was planned and manufactured.

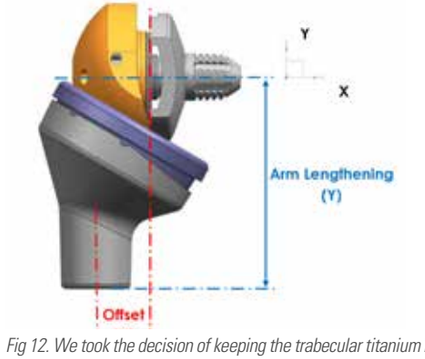

Fig 12. We took the decision of keeping the trabecular titanium base plate and lateralize the center of rotation. The only feature, which increases the offset without changing arm length value, is lengthening the glenosphere connector (to a specific maximal length, otherwise further mechanical tests are required).

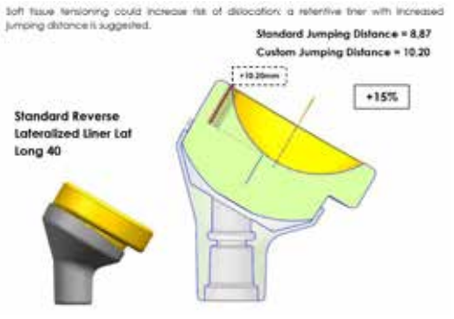

Fig 13. After simulating the new offset, the software suggested the usage of a custom retentive liner (constrained model) because soft tissue tensioning alone could increase the risk of dislocation. The risk of scapular notching was also evaluated.

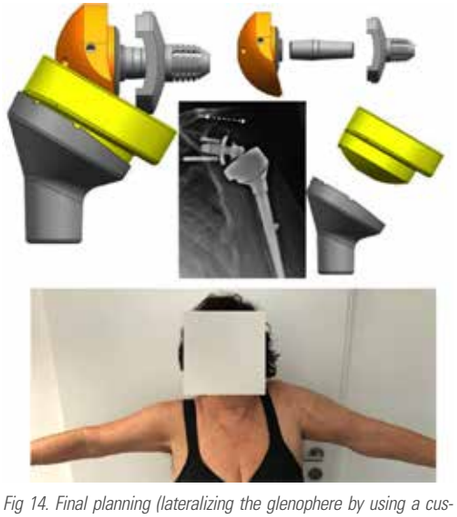

Fig 14. Final planning (lateralizing the glenophere by using a custom made glenosphere connector) and postoperative situation at 4 weeks

4th Case: Massive glenoid destruction after multiple failed revision surgeries (anatomic TSA to RSA, then RSA with glenoid tri-cortical bone grafting followed by loosening of the glenoid baseplate). Last surgery was conversion to CTA Hemiarthroplasty that became unstable in the last months.

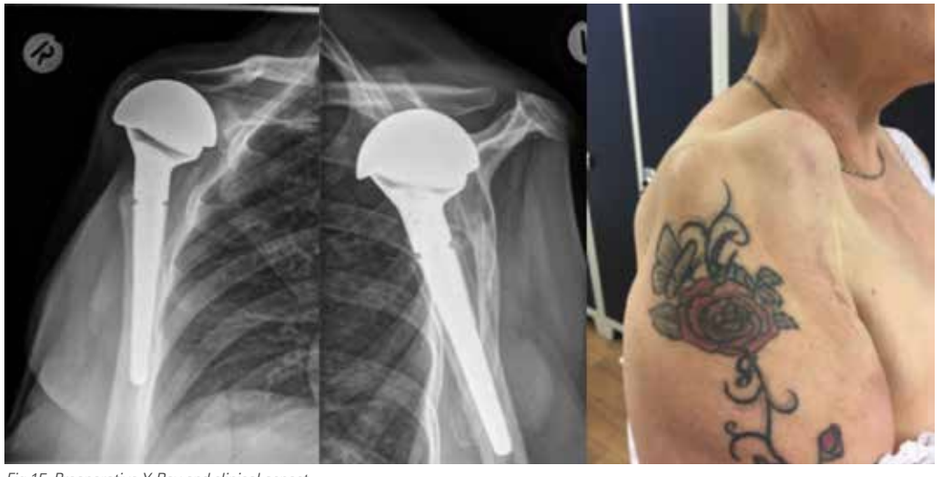

Fig 15. Preoperative X-Ray and clinical aspect.

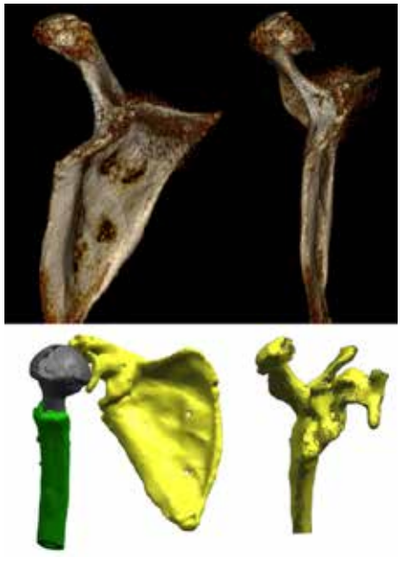

Fig 16. Preoperative 3D analysis of a dislocating CTA Hemiarthroplasty. Missing glenoid, chronic coracoid fracture and practically no possibility for a standard RSA or bone grafting.

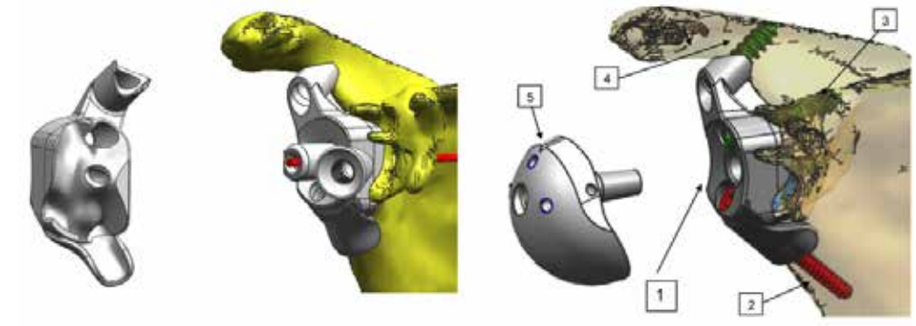

Fig 17. The solely option is to create a custom implant that can be safely anchored into the scapula body.

Fig 18. 3D printed anatomic model and the corresponding surgical guides.

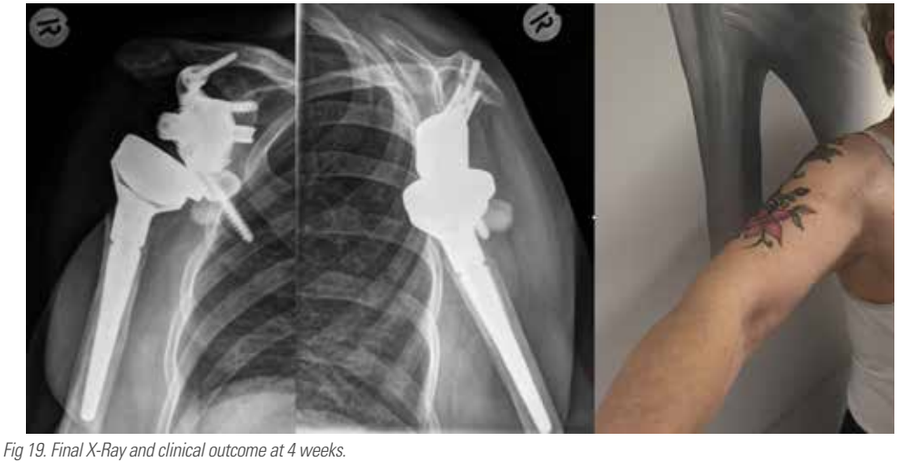

Fig 19. Final X-Ray and clinical outcome at 4 weeks.

CONCLUSIONS

Using patients specific implants for patients with severe bone loss and glenoid deformation in case of total or reverse shoulder arthroplasty seems to be a very promising approach. Our first experiences demonstrate excellent positioning of the custom-made glenoid components in the presented cases and excellent short-term results. A large portion of the difficulty of intraoperative reconstruction of glenoid and scapular geometry is transferred to the preoperative planning ("surgery before the surgery"), therefore probably rendering much more accuracy in the outcome. Because the implants are aligned with the shoulder's kinematic axis and the preoperative simulated range of motion shows no excessive stress into the bone-implant interface and trabecular titanium surfaces are used, we expect a well long-term performance of the RSAs and a durably improved quality of life for these patients.

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50/ COMPLICATIONS OF REVERSE TOTAL SHOULDER ARTHROPLASTY - HOW TO MANAGE FRACTURES OF THE SCAPULA?

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Reverse shoulder arthroplasty (RSA) prosthesis relies on medializing and lowering the center of rotation of the shoulder. Both have a significant effect on the deltoid muscle with recruitment of more muscle fibers and increasing muscle tension. The deltoid muscle origins from clavicle, acromion and spine of the scapula may observe increased constraint after reverse arthroplasty, potentially increasing the fracture risk in these areas. Fracture of the acromion or spine of the scapula are reported complications after reverse shoulder arthroplasty. In patients without preoperative acromial insufficiency, a fracture line through
the posterior acromion (acromial base fracture) or through the spine of the scapula can be observed either after a clear trauma or in the setting of sudden pain without trauma after RSA. In a review of postoperative events after RSA, Zumstein et al reported scapular fracture as the fourth most common complication (1.5%) behind instability, infection and aseptic glenoid loosening1. The reported prevalences of scapular fracture after RSA vary from 1% to 10.2%. The occurrence of a scapular fracture after RSA is a turning point for the patient and different treatment options are possible with either non-operative or operative treatment.

FRACTURE IDENTIFICATION

The management starts with the correct identification of the fracture line. Conventional radiographs are unreliable in diagnosing scapular fracture. Unless tilting of the fractured part of the scapula is obvious on plain radiographs, the fracture line identification and localization can be challenging because of the superposition with the clavicle on AP radiography. In addition, initial pain can be related to a non-displaced fracture before secondary displacement. The diagnosis can even be more challenging when a fracture occurs in the presence of a meso os acromiale. Therefore, a CT scan can be required to confirm the fracture.

In the literature, two classification systems for scapular fractures after reverse arthroplasty are used2,3. Crosby's classification includes preoperative scapular insufficiency (os acromiale, acromion erosion or fragmentation), visible on preoperative radiographs (type I). Preoperative scapular insufficiency is known to have little clinical influence on RSA functional results4 as it is a completely different entity from postoperative scapular fractures. True postoperative fractures are identified as a fracture line through the acromion just posterior to the AC joint (type II) and a fracture line through the posterior acromion or scapular spine (type III). Levy's classification does not include preoperative acromial insufficiency and is based on the amount of deltoid insertion involved by the fracture. Type I includes fractures through the midpart of the acromion, involving a portion of the anterior and middle deltoid origin. Type II is defined as a fracture involving at least the entire middle deltoid origin with a portion but not all of the posterior deltoid origin. Type-III fractures involved the entire middle and posterior deltoid origin.
We feel that most readers might be unfamiliar with these systems and better served by an anatomic description of the fracture with either an acromial base fracture or a spine fracture.

FRACTURE MANAGEMENT

Non operative treatment

We reported the results of this option in a series of nineteen cases with minimum 5-year follow-up5. There were 16 females (84%) and three males (16%). The average age at surgery was 74 years (range, 65 - 83 years). The average duration of follow-up after surgery was 98 months (range, 60 – 167 months).
The fracture occurred atraumatically, with sudden onset of pain in 13 cases (10 acromial fractures and 3 spine fractures) at a mean 3.3 months postoperatively (range 1 – 15 months). The fracture occurred within the first six months in 11 of the 13 cases (84.6%). Among these patients, five had no evidence of a fracture on plain radiographs and were further investigated with a CT scan that confirmed the diagnosis (3 acromial fractures and 2 spine fractures). The fracture occurred after a documented traumatic event in three cases at 2, 2.5 and 36 months respectively (mean 5.2 months). The fractures that occurred after these falls were all scapular spine fractures. The fracture was displaced in two cases and non-displaced in one case.

Three patients were diagnosed at the time of their final radiographic follow-up with a spine fracture. They were asymptomatic and the fracture had healed in two cases and resulted in a non-union in one case (112, 136 and 167 months, respectively). Careful review of clinical records and patient interview could not find a specific event to estimate the time of fracture occurrence.
The three patients who had asymptomatic fractures had no specific treatment. In the sixteen other cases, immobilization with an abduction splint was used for six weeks for pain relief. Patients were asked to resume daily activities as tolerated after the period of immobilization.

Radiographic results

Overall, non-union was observed in 11 cases and the fracture healed in eight cases.
In the acromion group, six cases had non-union and four cases healed. In the spine group, five
cases had non-union and four cases healed. Sixteen of the 19 fractures of this cohort were identified before the patient's final follow-up visit and were treated in an abduction splint. Among the 16 fractures treated with abduction splint, the fracture healed in six cases (37.5%). All fractures healed with some downward tilt, resulting in decreasing of acromion-greater tuberosity distance from pre-fracture status. Of the 16 fractures treated with an abduction splint, four acromial fractures out of 10 healed (40%). Two spine fractures out of six (33%) healed. Among the three unnoticed and untreated fractures, two were healed and one was not healed at last follow-up.
We found no relationship between screw placement in the baseplate and acromial base fractures. Four cases of scapular spine fractures demonstrated a fracture line in relationship with the tip of the superior screw (44%).

Clinical results

Our postoperative results show an average AFE of 109° and average CS of 47 points at minimum five-year follow-up. The results according to the fracture type are listed in Table 1.

	Series (n=19)			Acromial fracture (n=10)			Spine fracture (n=9)		
	Preop	FU	p	Preop	FU	p	Preop	FU	p
AFE (°)	60 ± 30 (20-120)	109 ± 39 (50-170)	0.002	60 ± 31.2 (20-120)	118 ± 37 (60-170)	0.019	61 ± 30.5 (20-100)	100 ± 41.2 (50-160)	0.058
Pain (pts)	4.3 ± 2.6 (0-10)	10.6 ± 4.7 (0-15)	<0.001	4.3 ± 2.7 (0-9)	11.4 ± 3.9 (5-15)	0.009	4.4 ± 2.8 (0-10)	9.8 ± 5.6 (0-15)	0.014
Constant (pts)	25.6 ± 10.6 (2-50)	47 ± 21.9 (8-81)	0.001	26.8 ± 10.5 (14-50)	52.1 ± 20.4 (17-81)	0.027	24.3 ± 11.2 (2-40)	41.3 ± 23.4 (8-79)	0.021

Complications/Reoperations

Two patients underwent open reduction internal fixation (ORIF) of a scapular spine non-union. A RSA was implanted for cuff tear arthropathy in one patient (Hamada 5). The spine fracture was diagnosed 2.5 months after the RSA and treated conservatively. Eight months later, there was no evidence of fracture healing with a painful shoulder and ORIF was performed (2 perpendicular AO plates). The non-union remained and hardware removal was performed 21 months after reoperation. At last follow-up (5 years after hardware removal), the patient was 89 years old, still painful (pain score 5 points out of 15), AFE was 90° and CS was 27 points.
In another patient, a RSA was implanted for massive cuff tear (Hamada 3) and the fracture was diagnosed seven months postoperatively. After a period of non-surgical treatment, a CT scan demonstrated a non-union of the index fracture. ORIF was performed (plating and tension band) with bone grafting. Two years later, the hardware was removed due to local irritation but the non-union was healed. At last follow-up (5 years after the last procedure), the patient was 85 years old, still painful (pain score of 5 points out of 15), AFE was 90° with a CS of 28 points.

OPERATIVE TREATMENT

ORIF is a described treatment but fixation of these fractures is challenging because of mechanical conditions due to deltoid muscle distraction forces combined with thin and osteoporotic bone. Crosby advocates ORIF in case of unstable spine fracture with good resolution of pain. Rouleau6 reported a successful fixation of a spine fracture (case report). Our experience is that failure of the fixation can occur requiring additional revision surgery. Various techniques of fixation have provided inconsistent results and even with updated data, there is no strong evidence that surgical fixation provides superior results compared to conservative treatment and further studies are required.

CONCLUSION

Acquired scapular fractures (acromion, spine) are a turning point in the postoperative course after RSA. Three diagnostic patterns occur: traumatic, atraumatic with sudden onset of pain, and the fracture unrecognized until appropriate imaging is performed. The fracture can

be recognized radiographically when immediate acromial/spine tilt occurs or in case of obvious fracture line. When no obvious fracture line is present a CT scan is recommended. Immobilization with an abduction splint frequently results in non-union or healing with malunion of the fracture. Final functional outcome is poor, regardless of acromial or spine fracture.
ORIF of a displaced/unstable fracture can be discussed but without reported evidence of superiority compared to non-operative treatment.

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51/ OPTIMIZING HUMERAL STEM FIXATION IN REVISION SHOULDER ARTHROPLASTY WITH THE CEMENT-WITHIN-CEMENT TECHNIQUE

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INTRODUCTION

Revision shoulder arthroplasty is a technically challenging procedure with inconsistent results.2-5 Studies have reported the advantages of retaining the humeral component,4-6 however, revision of the humeral prosthesis is often necessary in the setting of proximal humeral bone loss, humeral loosening or fracture, joint instability, implant malposition, and humeral shortening or medialization. Utilization of the reverse shoulder arthroplasty in the revision setting has allowed surgeons to overcome many of the difficulties surgeons face in the revision setting.
In revising a previously placed humeral component, arthroplasty surgeons are faced with the demand of attempting to salvage bone stock and creating a stable foundation for the revision stem. When revising a failed cemented humeral component, extraction of the stem and complete removal of the cement may be exceptionally difficult to obtain and can lead to severe loss of host bone stock, cortical perforation, and fracture.2, 3, 5, 16 In revision hip surgery implantation of a new cemented revision component in a retained cement mantle is a widely accepted technique.17-22 However, there is a paucity of literature regarding its application and performance in the shoulder. The purpose of this study was to define an ideal humeral working area and cement mantle for patients undergoing revision RSA using the cement-within-cement technique.
Materials and Methods:
A total of 87 patients from a period of 2004 to 2016 has been identified in chart review. Inclusion criteria were set as revision reverse arthroplasty in the setting of cement-within-cement technique. Pre-operative and post-operative radiographs for each patient were downloaded in DICOM (Digital Imaging and Communication in Medicine) format [Figure 1A] and analyzed in Mimics (v. 14.12; Materialise, Leuven, Belgium) [Figure 1B]. Total area of the cement (mm2) and total area of the humeral stem (mm2), as visualized on 2D image, was calculated for each subject in both pre-operative and post-operative radiographs.

MATERIALS AND METHODS

A total of 87 patients from a period of 2004 to 2016 has been identified in chart review. Inclusion criteria were set as revision reverse arthroplasty in the setting of cement-within-cement technique. Pre-operative and post-operative radiographs for each patient were downloaded in DICOM (Digital Imaging and Communication in Medicine) format [Figure 1A] and analyzed in Mimics (v. 14.12; Materialise, Leuven, Belgium) [Figure 1B]. Total area of the cement (mm2) and total area of the humeral stem (mm2), as visualized on 2D image, was calculated for each subject in both pre-operative and post-operative radiographs.

Figure 1A
Revision of previously cement humeral component to reverse prosthesis using the cement-within-cement technique. The patient's humeral component remained stable at their last follow-up (7.8 years).

Figure 1B
Preoperative and postoperative radiograph of patient who underwent revision reverse shoulder arthroplasty using the cement-within-cement technique after Mimics modeling

The study population was further stratified into two groups based on the diagnosis of radiographic humeral loosening. Group 1 consisted of patients who went onto develop humeral loosening after their revision RSA (n=8), and group 2 contained those patients who did not show signs of radiographic loosening after their revision RSA (n= 79).
Differences between areas of cement and areas of stem measured on pre-operative and post-operative radiographs were calculated for every patient. Furthermore, the filling ratio (area of the stem over the combined areas of the cement mantle and humeral stem) were calculated.
Averages and standard deviations were evaluated for every studied parameter. Measurement outcomes of the two groups were compared using the Wilcoxon-Mann-Whitney two-sample rank-sum test. Because of the limited number of revision episodes, no multivariable analysis was performed. Statistical significance was set at a P value < .05

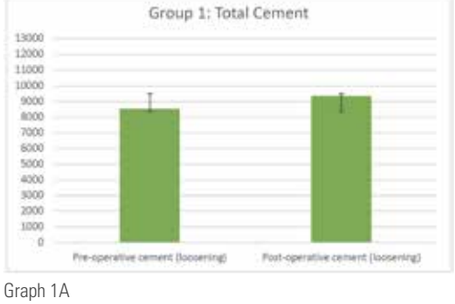
RESULTS

	Group1		Group 2	
	Pre-operative	Post-operative	Pre-operative	Post-operative
Total Area of Cement (mm^2)	8521±4355 (p= .006)	9332±3135 (p< .0001)	7784±5136 (p= .006)	12136±10950 (p< .0001)
Differences in Cement (mm^2)	811 (p<0.0001)		4353 (p<0.0001)	
Total Area of Humeral Stem (mm^2)	12353±8262 (p= 1.00)	6102±1261 (p= .285)	14010±10939 (p=1.00)	5790±5358 (p= .285)
Differences in Humeral Stem (mm^2)	6251 (p=0.845)		8220 (p=0.845)	
Filling Ratio	0.59 (p=0.259)	0.41 (p=0.833)	0.65 (p=0.259)	0.41 (p= .833)
Differences in Filling ratio	0.18 (p=0.272)		0.24 (p=0.272)	

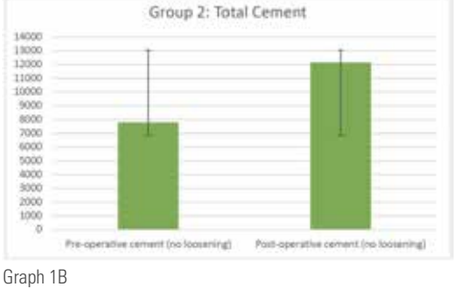
Table 1

In group 1 (loosening), it was found that difference in pre-operative and post-operative total area of cement was only 811 mm2 (p< .0001) (Graph 1A-C). However, the difference in group 2 (no loosening) was found to be an increase in 4,353 mm2 (p< .0001) of added cement. Furthermore, the difference in pre-operative and post-operative stem was found to decrease by 6,251 mm2 (p= .845) in group 1 (loosening), whereas the area of stem in group 2 (no loosening) decreased by 8,220 mm2 (p= .845) (Graph 2A-C).

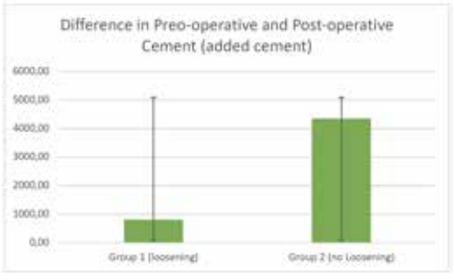
The pre-operative and post-operative filling ratio for group 1 (loosening) were found to be 0.59 (p= .259) and 0.41 (p= .833), respectively. The difference in the group 1 (loosening) filling ratio is 0.18 (p= .272). The pre-operative and post-operative filling ratios for group 2 (no loosening) were found to be 0.65 (p= .259) and 0.41 (p= .833), respectively. The difference in group 2 (no loosening) filling ratio is 0.24 (p= .272).



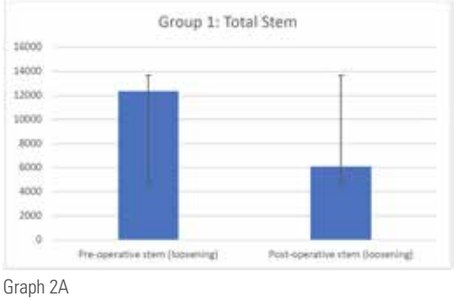
Graph 1A
Group 1 Total Area of Cement (mm2)



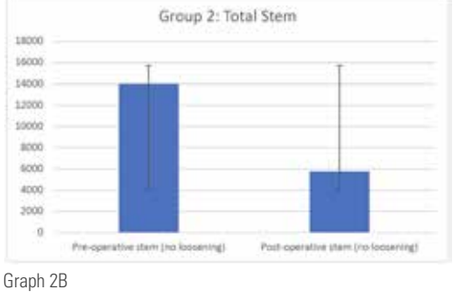
Graph 1B
Group 2 Total Area of Cement (mm2)



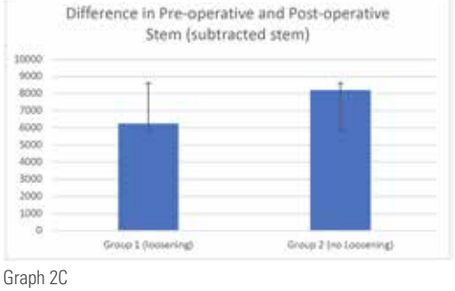
Graph 1C
Difference in Pre-operative and Post-operative Total Area of Cement (mm2) in group 1 (loosening) and group 2 (no loosening)



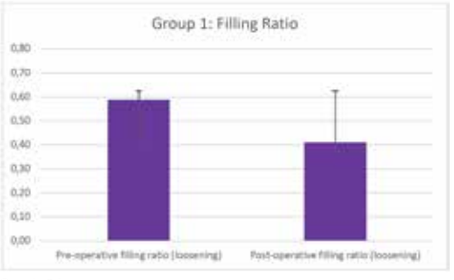
Graph 2A
Group 1 Total Area of Stem (mm2)



Graph 2B
Group 2 Total Area of Stem (mm2)



Graph 2C
Difference in Pre-operative and Post-operative Total Area of Stem (mm2) in group 1 (loosening) and group 2 (no loosening)



Graph 3A
Group 1 (loosening) Filling Ratio

Graph 3B
Group 2 (no loosening) Filling Ratio

DISCUSSION

In the setting of a previously cemented humeral component, revision reverse shoulder arthroplasty poses many challenges including component and cement removal, proximal humerus bone stock preservation, and establishing a stable foundation for the revision humeral stem.2, 3-6, 11, 16, 23-25 Wagner et al reported on utilization of the cement-within-cement technique in revision RSA with good medium-term survival rates, and good pain relief and functional outcomes with low complications, and low rates of humeral lucencies at follow-up.26 It is evident that the cement-within-cement fixation technique is an important consideration to preserve humeral bone stock, and humeral component and implant stability.2, 3, 5, 16 The purpose of this study was to define an ideal humeral working area and cement mantle for patients undergoing revision RSA using the cement-within-cement technique.

In our series of 87 shoulders that underwent cement-within-cement humeral component revision arthroplasty with a reverse prosthesis, we found that only 9% went on to develop radiographic loosening. In this group of patients, the difference in pre-operative and post-operative average added total area of cement was found to be statistically significant increase of 811 mm2 (p< .0001). In comparison to the 91% of patients who did not loosen, the difference of their average added total area of cement was found to be a statistically significant increase

of 4,353 mm2 (p< .0001). The group of patients that did not loosen received 5 times more cement on average than the group that did loosen.
Additionally, there was a reduction in total area of preoperative stem size to post-operative stem size of 6,251 mm2 (p= .845) in the group that loosened. However, a greater reduction of 8,220 mm2 (p= .845) was found in the group that did not loosen. Thus, the group that did not loosen used a stem that was nearly 1.5 times smaller than the group that loosened. Furthermore, the difference in the filling ratio (area of the stem over the combined areas of the cement mantle and humeral stem) in the group that loosened was 0.18 (p= .272), and the group that did not loosen was 0.24 (p= .272). These findings suggest that in order to achieve an adequate cement mantle with interdigitation in the prior cement and revision implant, it is preferred to use a smaller humeral stem than the previously implanted component. In addition, incorporating measures to maximize the cement volume utilized during reimplantation such as reaming the retained intramedullary cement mantle to allow for a greater volume of new cement may be considered.

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52/ THE STEM ABLATION RATING SYSTEM: A PREOPERATIVE SCORING SYSTEM TO GUIDE SURGEONS IN STEM REMOVAL DURING REVISION SHOULDER ARTHROPLASTY

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INTRODUCTION

Revision shoulder arthroplasty is increasing worldwide[1–4]. National registries and reference centers indicates that the most common etiologies for revision of hemiarthroplasty (HA) and total shoulder arthroplasty (TSA) are related to glenoid-sided problems or the soft tissues[5–7] while only few of them involve the humeral side. However, even if humeral loosening is a rare occurrence and remains around 5% in the literature[8–11], indications to change the humeral stem remain high. Recently, Merolla et al reported that only 10/157 (6.3%) humeral stems could be left in place during a revision procedure regardless of the indication for revision[12]. Indeed, most of the time, no existing convertible platform system is available for old implant designs, and often the orientation of the implanted stem, either height or version, prevents ideal soft tissue tensioning. The risk of fracture and subsequent excessive humeral bone loss when removing a well-fixed implant is high[13]. Additionally, humeral extraction can be time-consuming and associated with complications such as bleeding, hematoma, nerve palsy, vascular injury, and infection[14]. Therefore, providing surgeons with a preoperative tool that will prepare the surgeon for the difficulty of stem removal and providing them with a systematic method for the removal of each stem would likely reduce complications associated with this challenging problem.
The aim of our study was to determine which preoperative factors are relevant to predict the difficulty of extracting a humeral stem in revision of HA and TSA and to develop a preoperative predictive score that would grade the difficulty and assist the surgeon in addressing a stem revision procedure. Our hypothesis was that predictive factors for difficulty in stem extraction are present and identifiable on the preoperative radiographs and could be incorporated into a scoring system to help with intraoperative strategy.

METHODS

Sixty-two patients who underwent revision shoulder arthroplasty requiring stem extraction were evaluated. Inclusion criteria included: preoperative and postoperative radiographs, intraoperative video allowing for complete visualization of stem extraction and extracted humeral implants that could be analyzed for artifacts related to stem removal. All implants were identified and features of those implants that have been previously described as difficult implants to be removed were noted.
Three independent observers measured the preoperative radiographs, the intraoperative videos, and conducted the implant retrieval analysis. The preoperative radiographs were evaluated for the filling of stem or stem plus cement to the width of the canal at the middle of the humeral stem length, humeral radiolucencies, if the stem was cemented, and the stem type. The intraoperative videos were evaluated for the length of time of extraction, the number of hammer hits, and amount of proximal humeral bone removal. Finally, the retrieved implanted stems were evaluated for marks on the stem, marks on the flange, and the presence of residual bone or cement.
A STem Ablation Rating System (STAR System) was created based on previous radiographic features associated with difficult stem extraction (see Table I, Figure 1).

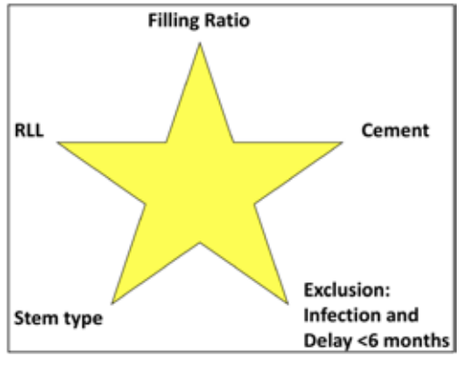

Figure 1
STem Ablation Rating System (STAR System)

An additional scoring system was used to grade the intraoperative extraction and the implant retrieval. (see Table II, and III). Each stem was then scored according to those 3 systems (Figure 2).

Table I: STAR System based on preoperative X-rays and difficult stem extraction

Filling rate (%)	**0**	**1**		
	≤ 60%	> 60%		
Cemented	**0**	**3**		
	N	Y		
RLL Score (/21pts)	x > 10	5 < x ≤ 10	0 < x ≤ 5	x = 0
	0	**1**	**2**	**3**
Difficult stem	**0**	**3**		

0 ≤ x ≤ 3	**Easy**
4 ≤ x ≤ 6	**Moderate**
7 ≤ x ≤ 10	**Hard**

Depuy Advantage, Arthrex Universal, Zimmer TM, DJO Turon Modular

Table II: Explant score (based on the extracted implant)

Stem Marks (/6)							
	0	**1**	**2**	**3**	**4**	**5**	**6**
	0	1-2	3-4	5-6	7-8	9-10	11-12
Flange mark (/2)	(Absence of flange = 2 pts)						
	0	**2**					
	N	Y					
Residual Cement or Bone (/2)		(Bone or Cement > 1cm²)					
	0	**2**					
	N	Y					

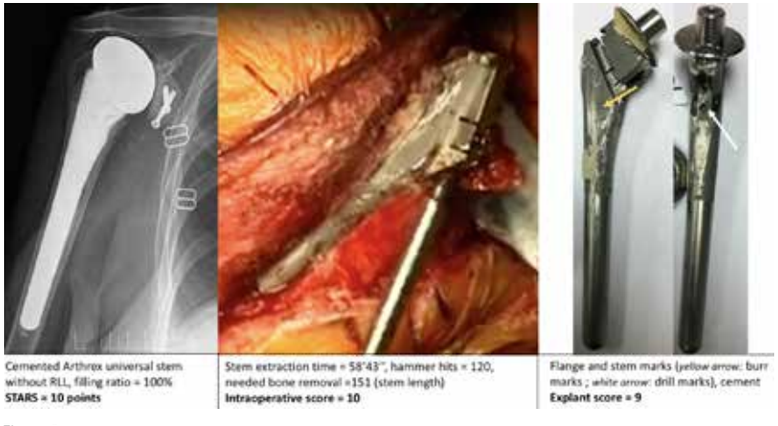

Figure 2
Case of a "hard" stem assessed according to the 3 used and correlated scoring systems

Table III: Intraoperative score (based on the video)

Time	**0**	**1**	**2**	**3**	**4**
	x ≤ 5s	5s ≤ x < 2min	2min ≤ x < 5min	5min ≤ x < 15min	x ≥ 15min
Hammer hits (nb)	**0**	**1**	**2**	**3**	**4**
	x = 0	0 < x ≤ 20	20 < x ≤ 50	50 < x ≤ 100	> 100
Proximal Bone removal mm	**0**	**1**	**2**		
	x ≤ 5	5 < x ≤ 20	> 20		

RESULTS

Of the 62 shoulders analyzed, 8 were excluded because of a time to revision less than 6 months from index procedure, or the presence of a documented infection. We performed the analysis on the remaining 54 revision surgeries. All three scores presented a strong and significant correlation ($p<0.001$) (Figure 3). Interobserver analysis showed an almost perfect correlation (0.945). The various intraoperative parameters that were chosen to determine the difficulty of the surgery were related to the STAR System.

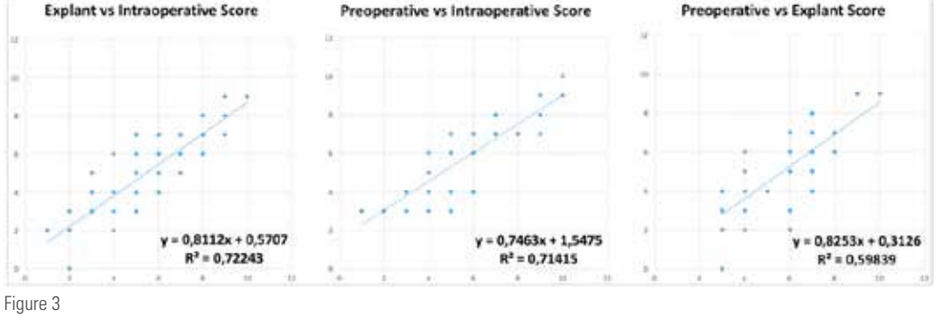

Figure 3
Correlations between the Preoperative, Intraoperative and Explant scores

Figure 4
Evolution of the various intraoperative parameters according to the STAR System

DISCUSSION

This study shows a reliable, strong correlation between the preoperative radiologic data and the intraoperative difficulties met while removing a humeral stem. Moreover, we developed a reproducible and reliable score that can help the surgeon in his strategy to perform revision procedure.

This study is the first that aimed to correlate the preoperative assessment to the intraoperative data and to develop a preoperative score. This was made possible thanks to the intraoperative videos saved from each revision procedure and the conservation of the stem explants that could be independently analysed by various observers and at different times.

A time to revision surgery from index HA or TSA less than 6 months and an active infection excluded patients from our analysis as the analysis would be biased in those cases. We identified four factors that predicted and increased the difficulty in the stem extraction: a low radiolucency rate around the stem, the presence a cement, a high filling ratio, and the type of implanted stem. Those parameters are already well described in the literature and are reliable[15–17]. We incorporated those factors into a preoperative score. We found that if the score was 7 points or more, the stem extraction must be considered "hard". In those cases, the surgeon would need to adapt his strategy: first the indication to remove a fixed stem must be correctly considered as it is sometimes possible to alter the metaphysis. If the stem needs to be extracted, the surgeon must anticipate the instruments needed to extract the implant (osteotoma, saw, burr) and the necessity of achieving a shaft windows or a longitudinal osteotomy. Finally, complications such as fissures/bone loosening are most likely to occur[4,18]. Another important finding was the need to determine the model of the current implant before the revision. It is essential in preparing sufficient instrumentation to extract the stem but above all we found that several stems were very much harder to remove than others due to their special coating or the presence of a proximal bone-ingrowth surface. Those characteristics have to be known previously by surgeons who have a regular activity in revisions knowing that the 10 most implanted stems represent more than 95% of the implanted stems in each country[7].

CONCLUSION

Preoperative assessment of radiographs can predict the difficulty of the stem extraction. The STAR System we developed is a reliable and reproducible score that can help surgeon in their daily revision activity.

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53/ GLENOID LOOSENING WITH REVERSE SHOULDER ARTHROPLASTY - EVALUATION AND MANAGEMENT

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BACKGROUND

Glenoid loosening was a significant concern when the reverse arthroplasty was first introduced. However the rate of glenoid loosening with reverse arthroplasty has been low. Over time, key factors have resulted in very low rates of loosening across a variety of designs. If the glenoid does loosen, there are techniques that can be used to revise to another reverse arthroplasty or revision to hemiarthroplasty. Revision to another reverse arthroplasty may employ new augmented glenoid components as well as custom glenoid components.

PREVENTION OF GLENOID LOOSENING: INFERIOR GLENOID TILT AND NEW TECHNOLOGY

The average glenoid has approximately 7 to 11 degrees of superior tilt. Creating inferior tilt is the key to preventing baseplate loosening. (1) Inferior tilt is traditionally created by reaming away central and inferior bone. Rather than reaming away this central and inferior bone, an augmented baseplate can used to create the inferior tilt. Benefits include: 1) less bone removal, 2) longer central and peripheral screws, 3) seating on hard subchondral bone and not soft cancellous bone, 4) lateralization with improved tension on the deltoid and the remaining rotator cuff, 5) decreased risk of scapular notching, and 6) less risk of greater tuberosity and acromial impingement. (Figure 1)

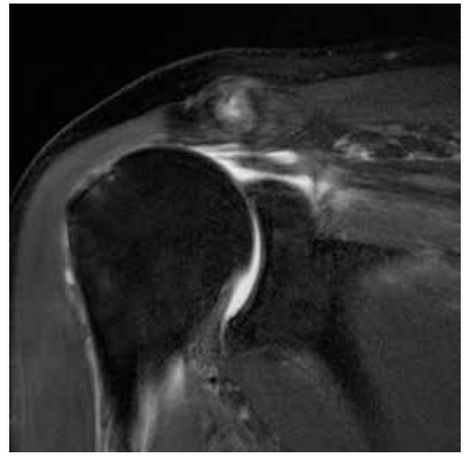


Figure 1 A)
MRI image demonstrating superior inclination of the glenoid

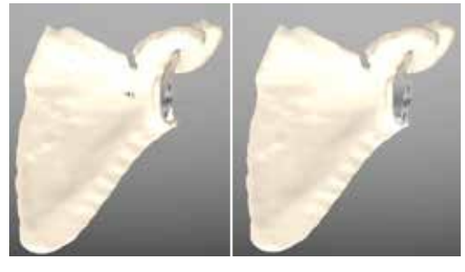


Figure 1 B) and C)
Traditionally, tilt was created by reaming away inferior and central bone. The augmented baseplate creates the tilt and preserves glenoid bone.

EVALUATION OF GLENOID COMPONENT LOOSENING

The primary reasons for glenoid loosening are excessive pre-operative glenoid bone loss, component malposition, excessive glenoid reaming, and infection. It is important to evaluate the pre-operative images, if they are available, to assess the amount of glenoid bone loss that was present at the primary surgery. In addition, it is helpful to look at serial radiographs over time for evidence of progressive glenoid lucency as well as assessment of glenoid component position. (Figure 2)

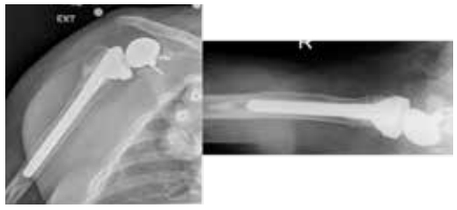


Figure 2 A and B)
Failed reverse arthroplasty that was placed with superior tilt

Figure 2 C and D)
Removal of the cemented stem and placement of a new baseplate

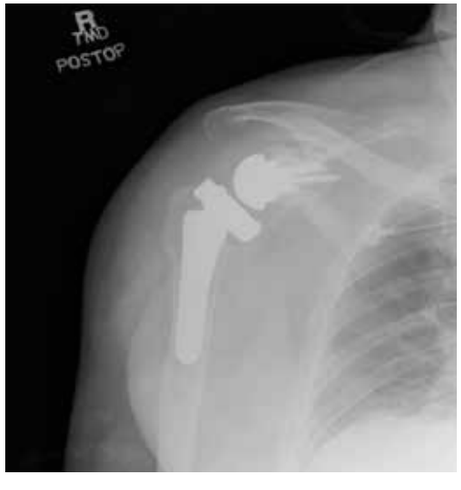


Figure 2 E)
Revision to a short stem reverse.

It is important to evaluate infection as a potential cause of glenoid loosening. It is imperative to determine if there is a history of wound drainage or post-operative use of antibiotics. Typically, the work-up of the patient with a loose glenoid component includes blood work: complete blood count, sedimentation rate, and C-reactive protein. Patients also undergo an image guide aspiration with cultures that are kept at least two weeks. A CT scan is also performed to evaluate loosening, but may be limited due to metal artifact even with metal suppression software.

REVISION

Counseling with the patient is very important to make a decision on proceeding with placing another glenoid baseplate or revision to hemiarthroplasty if the shoulder is not infected. Careful review of the imaging studies can give the surgeon a sense of the remaining bone stock. If the original glenoid position was poor, such as placed too high on the glenoid face, there may be enough bone remaining inferiorly to place a new glenoid component. In order to make up for the deficient glenoid bone, there are a variety of techniques that can be employed including use of autograft bone as well as allograft bone. Recently, surgeons have been using an augmented baseplate to make up for bone deficiency. In cases with severe glenoid bone loss; a custom Vault Reconstruction System can be used. (Figure 3) In a patient with an infection, the most accepted treatment is a two stage procedure.

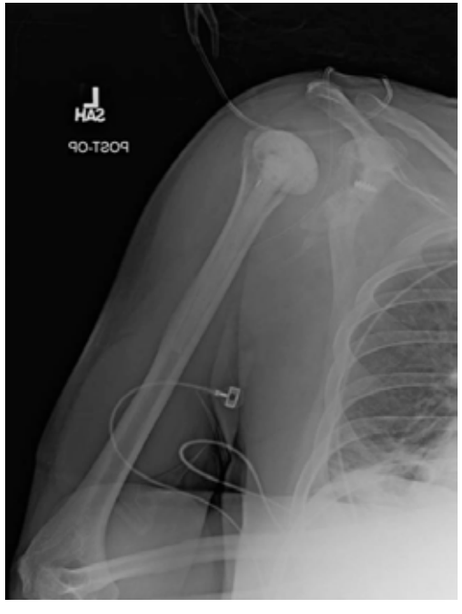


Figure 3 A)
Patient with a history of glenoid dysplasia and infection

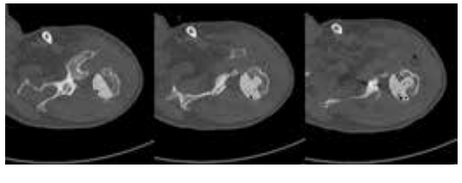
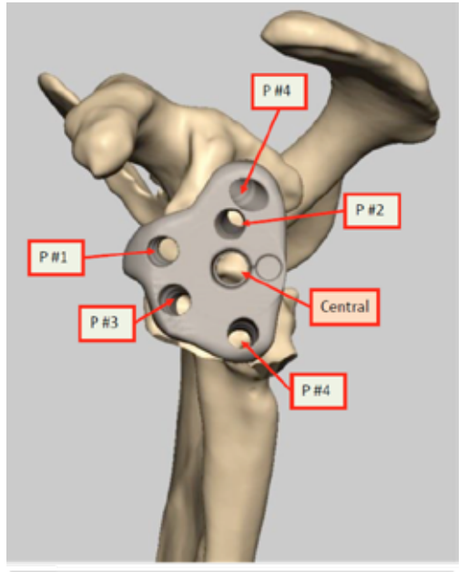


Figure 3 B)
Severe glenoid bone loss



US-20170685 - S_LOGSDE-0817LT-J_S			
Screw hole	L/N	Measured Purchase	Approximate Screw length*
P #1	L	23 mm to screw	15 - 20 mm
P #2	L	53 mm	45 mm
P #3	L	43 mm	40 – 45 mm
P #4	L	35 mm	35 – 40 mm
P#5	L	35 mm	35 – 40 mm
Central	N	35 mm	35 – 40 mm
Locking Screw Count:			5
Non-Locking Screw Count:			1
Total Screw Count:			6

Figure 3 C)
Pre-operative plan for the vault reconstructive system

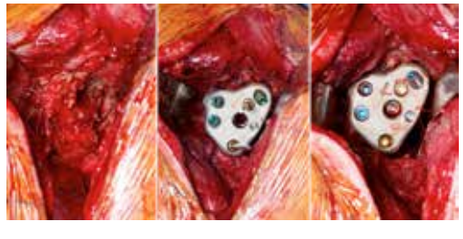


Figure 3 D)
Intra-op images of placing a custom glenoid baseplate

SUMMARY

Loosening of the glenoid component in reverse shoulder arthroplasty has become less common. When encountering this problem, the surgeon should carefully evaluate the remaining glenoid bone stock and evaluate reconstructive options. Additionally, there needs to be a high suspicion for infection and a work-up for infection may be beneficial

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54/ HOW TO MANAGE AN UNSTABLE REVERSE TOTAL SHOULDER ARTHROPLASTY: RETROSPECTIVE REVIEW OF 25 CASES?

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BACKGROUND

Although instability is the main complication after reverse total shoulder arthroplasty (RTSA), etiologies, predictive risk factors and management, remain not well understood. The most recent series estimate the rate of instability between 0 and 8%.[1,2]

In the most recent series about this complication, the causes are not well defined but the authors believe that instability after RTSA results from inadequate tensioning of the deltoid secondary to a shortening of the length of the humerus[3-5].

However, the etiologies of instability in RTSA are frequently multiple and the association of different factors is often underestimated. The main goal is to restore adequate tension of the soft tissue (deltoid and remaining cuff). This can be achieved by increasing both the lateralization of the humerus and that of the center of rotation of the joint.

In the literature, instability of RTSA is only reported as one complication among others (infection, glenoid loosening, humeral loosening etc.) but very few articles focus specifically on this complex condition[4,6].

The purpose of this retrospective study was to review all the cases of unstable managed in our group to analyze the causes, preoperative planning, the therapeutic strategy and the final result.

MATERIALS AND METHODS

Between 2008 and 2015, all patients who were managed for an unstable RTSA in our group were included. Patients who developed instability following trauma or neurologic damage(Axillary nerve or brachial plexus injury) were excluded. Twenty-five patients (14 women, 11 men, mean age at the time of index RTSA: 70 years old) who had been operated on in three institutions by three experienced shoulder surgeons met the inclusion criteria. The dominant side was affected in 20 cases.

The indication of the initial RTSA was: cuff tear arthropathy (12 cases), revision of a failed shoulder arthroplasty (5 cases), sequela of proximal humerus fracture (5 cases), complex acute fracture of the proximal humerus (2 cases), chronic locked dislocation (2 cases).

Timing of instability: 8 patients had an early dislocation at a mean 4 weeks postoperatively (range: 0-12weeks) while for the 17 others, the mean time of dislocation was 3 years postoperatively (range: 1-10 years). (Fig 1)

Figure 1
Anterior dislocation of a reverse shoulder arthroplasty. Malversion of the humeral stem combined with a superior tilt of the glenoid component

Preoperative planning was systematically done before reduction of the dislocation to identify the etiologies. Comparative standard radiographs including anteroposterior views of the shoulder in neutral, external and internal rotation, axillary views and outlet views to identify the direction of the dislocation. Medialization was systematically measured on the anteroposterior views in neutral rotation as the distance between the lateral edge of the acromion and the lateral cortex of the humerus. A contralateral radiograph was made to measure the length of the contralateral humerus in order to evaluate the shortening of the humerus leading to inadequate tension of the deltoid as described by Lädermann et al.5. A CT-scan with 3D reconstruction was obtained to evaluate the position of the humeral and glenoid implant, glenoid and humeral bone loss and fatty infiltration of the remaining cuff (subscapularis and teres minor, deltoid). A biological workup including blood count, sediment rate and CRP, procalcitonine was made preoperatively to look for signs of chronic infection.

Etiologies of instability were multiple

The causes of instability were identified. These included: inadequate length of the humerus (9 cases), superior tilt of the baseplate (4 cases), polyethylene wear of the humeral polyethylene bearing (4 cases); component loosening (6 cases: both components (2 cases), glenoid (2 cases), humerus (2 cases), infection (2 cases). In several cases inadequate length of the humerus was associated with another etiology. (Fig 2)

Treatment of instability

Two early dislocations without any implant malposition or loosening were successfully treated by closed reduction in the clinic. After reduction, these 2 patients were immobilized in a thoracobrachial cast to increase deltoid shortening and fibrosis of soft tissue.

The 23 remaining dislocations underwent surgery: open reduction (2 cases), exchange of the polyethylene humeral bearing to a thicker one (7 cases), revision of the humeral stem to position it more proud with exchange of the polyethylene humeral bearing to a thicker one (5 cases), exchange of the polyethylene humeral bearing for polyethylene wear (4 cases), revision of both humeral and glenoid components (5 cases). Those who had revision of both components, lateralization was obtained thanks to a humeral stem with an inclination of 135° and a center of rotation of the joint lateral to the bone-implant interface. Lateralization increases the wrapping angle and the compressive forces of the deltoid. Infection (2 cases).

Figure 2
RSA after a failure of hemiarthroplasty indicated after a conservative treatment for complex proximal humeral fracture. Inferior and anterior dislocation. The glenoid component is standard with a COR at the level of the glenoid. The inclination of the humeral cut is 155°. Prosthesis is medialized and potentially instable. Causes of instability are multiple.

Surgical technique

All revisions were performed through the previous deltopectoral (12 cases) or superolateral (13 cases) approach in the beach chair position under general anesthesia with an interscalene block. Through the deltopectoral approach, we were able to repair the subscapularis in only 30% of the cases.

Several problems had to be addressed during these revision procedures. These can be grouped as follows: excessive shortening of the humerus, excessive medialization of the glenosphere, glenoid loosening with poor glenoid bone stock, septic loosening of both the humeral and glenoid components.

Management of humerus shortening (9 cases) (Fig 3)

When the humeral shortening was less than 10 mm compared to the contralateral side, the polyethylene humeral bearing was exchanged to put a thicker one in order to restore proper length of the humerus and a better deltoid tension. When the shortening was found to exceed 10 mm, the humeral implant was revised to position it in the

more proud position. When shortening was found to exceed 5 cm, either a massive custom-made humeral stem or a massive allograft were used to restore the length of the humerus.

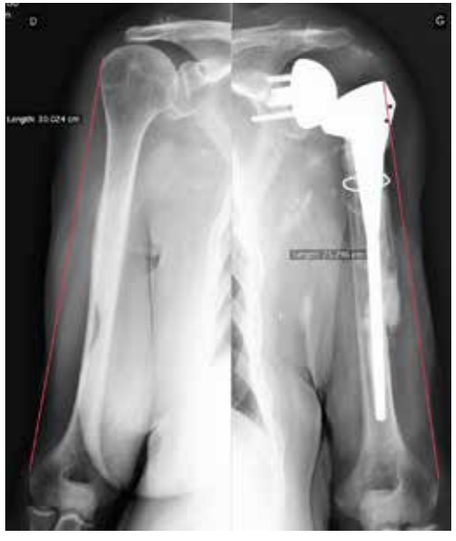

Figure 3
The key point is to measure the length of the contro lateral humerus. With a contralateral radiograph. In this case there is a shortening of the humerus of 5 cm and an inadequate tension of the deltoid. The causes of the instability were multiple: medialization of the prosthesis; shortening of the humerus; no subscapularis

Management of glenoid loosening with poor glenoid bone stock (8 cases)

In the cases where instability was due to glenoid loosening, the glenoid implant was revised. In this setting, the glenoid bone stock was found to be very poor and a metal-backed glenoid implant prolonged by a metallic long post combined with cancellous bone autograft was used to obtain a strong primary fixation. This implant allows a metallic lateralization of the center of rotation of 8.5mm. With the superior bone graft, the inferior tilt increases compressive forces to decrease the risk of micromotion and shearing forces applied at the bone-implant interface. A glenosphere size 39 was implanted in 5 cases and size 36 was used in the 3 others. The metallic lateralization of the glenoid implant combines with an humeral inclination of 135°allow to reduce the size of the bone graft(Iliac crest , coracoid process or allograft).

Management of excessive medialization (2 cases)

In 2 cases, a well fixed glenoid implant (Delta Xtend, DePuy, Warsaw, IN) had to be replaced because of an excessive medialization of the joint. Indeed, because of this, the soft tissue (deltoid and remaining cuff) where insufficiently tensioned and this led to instability. In case of persistent instability despite correction of the humeral length and exchange to a glenosphere size 39, excessive medialization is often implicated. To restore the stability of the prosthesis we had to lateralize both on the humeral size (135° inclination of the humeral cut) and on the glenoid size (metal-backed implant with a lateralized center of rotation). The lateralization of the humerus increases the « wrapping angle » of the deltoid and therefore its compressive forces leading to an improvement in stability[7]

Management of infection (2 cases)

Irrigation and debridement were performed in association with a total revision of both the humeral and glenoid components. The diagnosis of infection was done preoperatively on biologic signs and confirmed by the intraoperative aspect and by tissue culture. A double antibiotic therapy was prescribed for 3 months adapted to the antibiogram. Both patients healed uneventfully are no longer infected.

Post-operative management

All the patients were maintained in an abduction sling for four weeks post operatively. Physiotherapy was not started before the fourth postoperative week. A systematic double antibiotic therapy was set up which was stopped when cultures were negative in more than three samples taken or modified according to the results.

Clinical evaluation

Clinical evaluation was done pre- and post-operatively by the senior authors. We assessed the pain score using the Visual Analog Scale (VAS), the absolute Constant score[8], the simple shoulder test (SST)[9] and the Simple Shoulder Value (SSV)[10] .Patient satisfaction was graded subjectively according to a four point rating scale as: very satisfied (4), satisfied (3), acceptable (2) and worse (1).

Radiological evaluation

During the post-operative visits, the patient did routinely a standard AP-view with neutral, internal, and external rotation and an axillary lateral view to evaluate scapular notching, component migration or loosening, fractures of the acromion or of the scapular spine. If the patient remained painful after a few months without any clear sign of loosening, a CT-Scan wit 3D reconstruction was performed.

RESULTS

Clinical outcomes

No patient was lost to follow-up and the minimum follow-up after the revision procedure for instability was 12 months (mean, 36 months; range, 24–40 months). The mean VAS was 0.4 (range; 0-2). The mean SSV was 54.2% (range; 20 – 80). The mean Absolute Constant Score was 48.8 (range; 33-74). Active flexion was significantly improved to a mean 102° (range; 30°-170°). Active external rotation with the elbow on the side was significantly improved to 20° (range; -40°-40°) and with the arm held in 90° of abduction from a mean 30° (range; 0°-20°) to a mean 45° (range; 0°-90°). The mean final SST was six "yes". Subjectively 6 patients were very satisfied, eleven were satisfied, 6 considered their results acceptable and the last 2 estimated their result as worse than before the surgery. In this series, we did not find any correlation between the risk of dislocation and the approach (12 deltopectoral, 13 superolateral) or the gender (14 females, 11 males). On the opposite, more than 50% of the patients had been operated before their RTSA and the subscapularis was found to be irreparable in 30% of the patients and for the 70% who had no rupture of the subscapularis, the mean fatty infiltration was 3.3.

Radiological outcomes

In 2 cases the baseplate shifted in position under the acromion but this did not lead to any pain. No periprosthetic lucency, no scapular notch, no fractures of the acromion or of the scapular spine were observed at last follow-up. (Fig 4)

Figure 4
We revised completely the prosthesis/ An allograft of 5cm was mandatory to restore the length of the humerus and the wrapping angle of the deltoid. To restore the lateral offset, and a retensionning of the deltoid and the remaining cuff we did a metallic lateralized glenoid component with an inferior tilt and we used a lateralized humeral stem with 135° of inclination

DISCUSSION

Despite good results after RTSA, high rates of instability have been reported. Most series, particularly those with a large proportion of revision cases, have reported a rate of instability varying between 1 to 8%.[11, 12]

Instability of RTSA remains a difficult problem to solve. Shoulder surgeons should be able to identify the causes of instability and to determine a therapeutic plan to stabilize the prosthesis and to avoid general complications in this elderly and fragile population. In our retrospective review of 25 cases, the main cause of instability was an inadequate tension of the deltoid caused by an excessive shortening of the humerus. Therefore, it appears essential to perform contralateral comparative radiographs systematically to measure precisely the shortening according Lädermann et al.[5].

Standard radiographs can easily eliminate glenoid or humeral loosening. CT scans and 3D reconstruction are mandatory to precisely quantify bone loss before revision. Infection should be carefully excluded after clinical and biologic explorations and eventually synovial fluid aspiration and fluid culture. The most difficult cause of instability to recognize and to treat is an insufficient lateral offset of the prosthesis with an excessive medialization of the center of rotation and a humeral shaft inclination of 155°. In order to increase the lateral offset several options are available. The glenosphere can be changed to a larger size glenosphere (size 39 or 42) and the humeral polyethylene bearing can be a changed to a thicker one creating a small lateralization. If this is not enough, both components can be changed. The center of rotation can be lateralized by a metallic lateralized baseplate or by a bone graft (BIO RSA). The humeral component can be changed to a component with a smaller neck-shaft angle (under 145°). The goal is to retension the remaining cuff and deltoid to increase the wrapping angle and the subsequent compressive forces to the joint. In some cases, the cause can only be identified intraoperatively: a mechanical impingement of the implant against the scapular neck is observed when the arm is placed in adduction. This situation can be seen especially with first generation RTSAs which have a center of rotation at the level bone-implant interface and a neck-shaft angle of 155°.

Regarding the treatment, in our series only 2 cases (8%) were reducible with a closed reduction. These results diverge from the findings reported by Teusink et al. and Chalmers et al.[13] who found 62% and 44% of success after closed reduction. Twenty-three patients (92%) returned to the operating room for open reduction.

A point which is still controversial is the function of the subscapularis for the stability of the RTSA. Edwards et al[14] prospectively compared dislocation rates in patients with reparable and irreparable subscapularis tendons during RTSA and found a higher rate of dislocation in the irreparable subscapularis group. Clark and colleagues[15] retrospectively analyzed subscapularis repairs in 2 RTSA groups and found no appreciable effect on complication rates, dislocation events, gains in range of motion, or pain relief.

This retrospective study has some limitations. We did not analyze the body mass index (BMI) and the previous indication of the RTSA. Padegimas et al.[16] found a higher risk of instability in patients with a higher BMI and in revisions of RTSA

CONCLUSION

Unstable RTSA is not so rare and represents a difficult challenge for the shoulder surgeon. One or two or more causes have to be identified before the revision. Bilateral radiographs, CTScans and biologic exams must be systematic. Closed reduction is rarely a success and open reduction with revision of some or all the components of the prosthesis is often mandatory. The restoration of an appropriate humeral length and lateralization of the prosthesis to increase the tension of the deltoid are crucial to stabilize the shoulder.

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