CURRENT CONCEPTS REVIEW

Short Stems and Stemless Shoulder Arthroplasty: Current Concepts Review

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Abstract

Historically, the shoulder arthroplasty humeral component has been designed for the management of infections, tumours and fractures. In all these cases the stem was needed as a scaffold. Original humeral components were not developed for use in shoulder arthritis, so these designs and derivates had a long stem. The newest humeral implants innovations consist in shortening of the implant, or even removing the whole stem, to rely on stemless fixation at the level of the metaphysis. This implies the advantages of preserved bone stock, less stress shielding, eliminating the diaphyseal stress riser, easier implant removal at revision, and humeral component placement independent from the humeral diaphyseal axis. Nowadays, surgeons try to balance the need for a stable fixation of the humeral component with the potential need for revision surgery. Complications of revision shoulder arthroplasty are related to the need for removing a well-fixed humeral stem, the length of the procedure, and the need to treat severe bone loss.

Level of evidence: V

Keywords: Bone preservation, Reverse total shoulder arthroplasty, Revision surgery, Shoulder resurfacing, Short stems, Stemless shoulder replacement, Total shoulder arthroplasty

Introduction

Since the original Neer's humeral replacement in the 1950s, the primary anatomic total shoulder arthroplasty (TSA) design has evolved (1). The newest humeral component innovation was shortening the humeral component to rely on stemless fixation in the humeral metaphysis (2). Evolution of implants and technique have led to a substantial increase of the number of primary shoulder arthroplasties performed over the past decade. Accompanying this exponential increase, the incidence of revision shoulder arthroplasties is expected to increase as well. The estimated rate of revision for failed shoulder arthroplasties has grown by 400% over the last 20 years, making revisions account for up to 10% of all shoulder arthroplasties (3–6). Complication rates of revision total shoulder arthroplasty (TSA) have been reported to be as high as 36% to 48% (4,7).

The management of a failed shoulder arthroplasty is a complex and difficult problem for the shoulder surgeon, with potential difficulties and complications. They are related to the length of the procedure, the need to remove a well-fixed stem (whether cemented or cementless), and the need to deal with severe bone loss (8). Intra- and postoperative complications, as well as technical difficulties during revision surgery are mainly related to the diaphyseal humeral component (9). To avoid the need to remove a well-fixed humeral stem, which often requires performing a humeral window, surgeons may have to consider the use of stemless implants (10–13).

In this narrative review, the most important aspects of short stems and stemless shoulder arthroplasty are highlighted.

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Historical perspective

Many years after Neer's first design, Levy et al changed the world perception about the humeral component in TSA (1, 2). Since these authors published their first report about stemless humeral components, there has been a lot of controversy about how to optimally fix a humeral component in the humerus (2). Initially, cement fixation of the humeral component was considered to be mandatory (14). Later on, this was shown to be no longer necessary in second- and third-generation implants (15–17). In surface replacement arthroplasty, only a shell of bone is resected from the humeral head and the humeral shaft is left intact with no diaphyseal component; therefore it can be considered as easier to revise (2,18–21).

Isolated humeral stem loosening is a rare complication in the absence of infection. This has led surgeons and industry to question how long the humeral component of a shoulder arthroplasty needs to be. Surgeons are constantly balancing the need for a primary stable fixation of the humeral component with the need for possibility to revise it if needed, because of complications like infection or fracture (16). The only indications for the use of a stemmed implants are in four- part fractures and in those patients with severe destruction of the humeral head such that no surface remains to be replaced (2).

Rationale of Mechanism

More than a decade ago, it has been shown that clinical outcomes can be considered similar to those of conventional stemmed prosthesis can be reached by using stemless humeral implants (2). These reports started to suggest that the humeral component does not need a stem or cement for fixation (2). In their initial series, 93.9% of the patients considered their shoulder to be much better or better after surgery (2). Boileau et al published the results of their prospective clinical series, in which they confirmed the hypothesis that stemless shoulder arthroplasty does not negatively impact the short-term outcomes (22). Berth et al examined the clinical and the radiological results in 82 patients with primary osteoarthritis (OA) of the shoulder treated with either a stemless shoulder prosthesis or a stemmed shoulder prosthesis to detect possible differences in the functional outcome and to evaluate radiological properties of the implants. Their results showed that the use of the stemless shoulder prosthesis yielded good outcomes which, in a mid-term follow-up, were comparable with those provided by a standard anatomic shoulder prosthesis (23).

A prospective randomized trial evaluated the clinical and radiographic outcome of a stemless replacement of the humeral head compared with a standard fourth-generation stemmed shoulder prosthesis (24). Total shoulder arthroplasty was performed in 20 patients with a stemless shoulder prosthesis and in 20 patients with a standard stem humeral head replacement. The functional outcome obtained in this series using a stemless humeral head implant, showed a significant improvement of the Constant score (CS) from 54 preoperatively to 73 at the minimum of 5-year follow-up, and was comparable to

the results after shoulder arthroplasty using a stemmed fourth-generation shoulder prosthesis, with an increase of the CS from 26 preoperatively to 70 postoperatively (24). Likewise, a quasi-randomized clinical trial was performed to compare the stemless ongrowth humeral implant with a standard cemented, stemmed TSA implant (23). Although no differences were noted with respect to clinical outcomes, implant survival, or radiolucent line formation, the stemless implant reduced surgical time by 15 minutes and reduced blood loss by 100 mL (23). This study was conducted by Berth et al and published in 2013, and comprised 82 patients with primary OA. 41 patients received a stemless procedure, and 41 were treated using a stemmed prosthesis. They noted a mean postoperative CS of 55 after a stemmed implant vs. a CS of 49 after a stemless implant at a mean follow-up of 31 months and 33 months, respectively. The mean active range of motion for the stemless group was 116° of forward flexion, 105° of abduction, and 54° of external rotation vs. 103°, 97°, and 49°, for the stemmed group (23). In the same line, a randomized prospective trial conducted by Mariotti et al, included 29 patients with primary OA. Ten patients received a stemmed implant, and 9 patients received a stemless implant. At a follow-up of 2 years, a CS of 93 was observed for the stemmed group, and a CS of 88 was observed for the stemless group (25).

Cementless surface replacement arthroplasty (CSRA) of the shoulder differs in many aspects from a non-constrained stemmed shoulder prosthesis. The concept of the resurfacing consists on replacement of only the damaged joint-bearing surfaces and attempted restoration of normal anatomy with minimal bone resection. The components are not placed in any fixed angle of inclination, retroversion, or offset but pretend to mimic the patient's anatomy. One of the benefits which is achieved by the resurfacing or stemless replacement of the humeral head, is the reconstruction of the rotational centre independent of the axis of the humeral shaft (26).

The primary goals of humeral implant design include replication of the articular anatomy to restore physiologic soft-tissue tension, providing early implant stability and long-term bony fixation, and pretending to avoid potential complications, such as aseptic loosening, periprosthetic fracture, and proximal humeral bone loss resulting from osteolysis and stress shielding. One of the reasons Neer developed a stemmed (1), unconstrained prosthetic replacement of the proximal humerus was specifically to provide a scaffold to re-build acute 4-part fractures (14).

There are at least five reasons why resurfacing and shorter humeral components may be advantageous: preserved bone stock, less stress shielding, no diaphyseal stress riser, ease of stem removal at revision, and humeral head placement independent from the anatomic axis.

The first reason why shorter humeral components may be beneficial is that bone stock is preserved. Leaving more proximal bone untouched increases probabilities for fixation. If a humeral stem loosens, the cortical bone destruction can occur at the tip of the stem meaning that each subsequent revision needs to extend further

distal (27).

The second reason is avoiding the stress shielding of the proximal humerus. Metaphyseal fixation ensures that as much bone as possible is loaded (17). Raiss et al. described radiographic evidence of stress shielding in as many as 82.5% of traditional humeral components (15). The diaphyseal portion of a humeral stem may transfer some of the load away from the proximal humerus and can generate osteopenia (28).

Third, metaphyseal stems will avoid a diaphyseal stress riser. Lee et al. have shown that reaming the diaphysis causes a stress riser even before the component is inserted since the canal is often reamed asymmetrically (29). Periprosthetic humerus fractures are due to the stress riser in diaphyseal humerus bones (30). Moving the stress riser to proximal metaphyseal bone may reduce the possibility of potential fracture, or at minimum preserves distal diaphyseal bone stock for potential fixation or revision surgery.

Fourth, revision of the humeral component is technically less complex and revision surgery is less aggressive. The use of shorter components will make revision easier (16,31). Bone stock should be preserved whenever possible. No matter how successful the prosthesis, a small number will fail and require revision. Even with improved cementing techniques there will be considerable bone loss should infection or loosening occur. Loss of bone stock involves the use of larger prostheses and more cement, but if the uncemented surface replacement were to fail, only the amount of bone that lies immediately beneath the humeral cap would be lost.

Finally, for the placement of stemmed humeral components, a near anatomic relationship between the humeral head and the humeral shaft axis may be required (32). The essential advantage of the resurfacing and stemless implants is the fixation of the humeral component without the need to prepare the humeral diaphysis. Therefore, the humeral head can be positioned regardless of the shape of the humeral diaphysis. This fixation technique is particularly useful in patients with posttraumatic osteoarthritis OA of the shoulder, fracture sequelae and deformities in the metaphyseal region (23). Besides that, among different shoulders there is little variation in the size of the glenoid and the head of the humerus, but anatomical version and inclination may vary greatly (33). An important geometrical variation is the posterior offset (34). The native head of the humerus is not centred on the shaft, but offset posteriorly and medially. Stemless designs provide surgeons the opportunity to reconstruct the proximal humerus without relying on the humeral diaphysis for alignment or fixation since they do not have a shaft portion to the component (35).

Evidence supporting the use of stemless humeral implants

Bone preservation is becoming a major goal in shoulder replacement surgery (11,36). Some stemless implants may differ from resurfacing implants because resurfacing implants require reaming of the articular surface but do not involve osteotomy of the humeral neck. Metaphyseal

cementless implants without a diaphyseal stem have been developed to preserve bone and resect only a minimal amount of bone (11,37–39). Even in the context of reverse total shoulder arthroplasty (rTSA), the short metaphyseal design without a diaphyseal stem has shown encouraging short- to midterm results, with excellent pain relief and shoulder function, restoration of good active range of motion, and high patient satisfaction scores (11) [Table 1].

In the early 1980s the idea of developing a shoulder joint prosthesis specifically for use in less affected arthritic shoulders by use of a surface replacement arthroplasty was introduced (40). A few years afterwards, the Copeland shoulder resurfacing arthroplasty was developed. This prosthesis was conceived to allow the surgeon unlimited flexibility to adapt the prosthesis to the patient's own anatomy rather than imposing the prosthetic anatomy on the patient. For this development, 20 cadaver shoulders and 20 dry bone specimens together with 200 radiographs of normal shoulders to assess the normal anatomical variation were used. These measurements were subsequently confirmed by Boileau and Walch, and three sizes of prosthesis were developed (33).

The design concept consists of surface replacement with minimal bone removal, cementless fixation with primary press-fit mechanical fixation, and hydroxyapatite coating to promote biological fixation with bone ingrowth. Bone removed for the central drill hole for the prosthesis can be used for grafting any defects under the humeral cap so that no bone is wasted. With this implant, no complicated instrumentation is necessary to calculate angles of version, inclination (33), or offset (34). A comparative summary highlighting advantages and disadvantages of both stemmed and stemless implants is shown in table 2.

Shoulder resurfacing

The first stemless implants ever (Mark I prosthesis), had a central pegged humeral component, which was secured initially with a screw from the lateral side of the proximal humerus, combined with a polyethylene glenoid element stabilised by a cementless finned peg. It was soon seen that the screw was unnecessary. Some became loose and had to be removed. In vitro testing suggested that it did not contribute to fixation. In 1990 the Mark-2 prosthesis was introduced which added metal backing to the glenoid component and a fluted taper fit peg to both constituents. In the Mark-3 model hydroxyapatite coating was added and this has been in use since 1993 [Figures 1; 2].

The indications for surface replacement arthroplasty are the same as for any other type of shoulder replacement and include pain and disability arising from the glenohumeral joint arthritis as result of primary and secondary osteoarthritis, rheumatoid arthritis and other inflammatory arthritis, posttraumatic arthritis, avascular necrosis, instability arthropathy and glenohumeral deformity with secondary arthritis.

One of Levy and Copeland's initial series was comprised between 1986 and 2000, and included 285 surface replacement arthroplasties (2). The best results were achieved in primary osteoarthritis, with CS of 93.7% for

SHORT STEMS AND STEMLESS SHOULDER ARTHROPLASTY

Table 1. Summary of the most important studies describing the outcomes with short stems and stemless implants										
				Results						
Author	**Year**	**Nº of cases**	**Model TSA Constant score / age-adjusted**	**ROM (degrees)**				**Satisfaction**	**Pain**	**Complica-tions**	
				Elev	**Abd**	**ER**	**IR**				
Levy et al.(11)	2016	102	Cementless stemless	59 / 86	129	-	51	65	85/100	-	21 notching
Collin et al.(22)	2017	47	Stemless TSA (Simpliciti system)	69	131	-	15	6.8/10 points	87%	-	2 revisions 17 radiolucents
Berth & Pap (60)	2013	82 (41/41)	Affinis (Mathys) - Stemmed shoulder proth	26.3 +/- 5.7	72.8	63	30.1	-	-	13/15 (1.7 points)	1 Hematoma++ 1 Wound infec-tion
			Total Evolutive (Biomed) - Stemless shoulder system	30.1 +/- 7.1	81.2	68.2	39.1	-	-	13/15 (1.8 points)	1 glenoid fracture 1 temporary brachial plexus neuropaty
Uschok et al.(24)	2016	40 (20/20)	Stemless Eclipse prosthesis	72.8	154.3	149.3	48.6	-	-	12.7/15 (2.4 points)	1 Atraumatic loosenig of glenoid comp 1 RCD
			Univers II standard shaft prosthesis	69.9	149.3	131.3	44.7	-	-	12.4 /15 (2.1 points)	1 Traumatic loos-ening (fx greater tuberosity)
Mariotti et al.(25)	2013	19 (10/9)	TSA stemmed	93.2 +/- 9.5	165	160	51.5	5.4	SST+ 10.5 +/- 2.27	-	None
			TSA stemless	88 +/- 12.46	151	137.78	45.55	5.55	SST+ 9.67 +/- 2.45	-	None
Habermeyer et al.(61)	2015	78	Eclipse stemless shoulder prosthesis (Arthrex)	65 +/- 16.3	140.7	129.9	44.2	-		12.9 (2.2 points)	None
Ballas & Béguin(37)	2013	56	Total Evolutive reverse Shoul-der System prosthesis (Biom-et) - anatomical & reverse	62	140	-	45	-	-	12/15 (3 points)	1 partial humeral fracture 1 superficial infection 1 hematoma 1 stress fracture acromion (4 years postop) 1 scapularis rupture (1 year postop)
Kadum et al.(38)	2013	37	16 stemless / TSA anatomic & reverse	QuickDASH 29	110	110	-	L3	EQ-5D# 0.74	VAS* 10	
			21 stemmed	QuickDASH 35	90	90	-	L4	EQ-5D# 0.73	VAS* 0	1 loosening
Teissier et al.(39)	2015	96	Total Evolutive Shoulder System prosthesis (Biomet) - stemless & reverse	68	143	138	39	4	-	2/10	1 instability 1 spine stress fracture 19% scapular notching
Atoun et al.(45)	2014	31	Metaphyseal stemless, reverse shoulder prosthesis (Verso, Biomet)	56.2 / 80.2	128.5	116.5	50.8	64.6	8.5/10	12.5/15	
Schnetzke et al.(62)	2015	82	TSA with a short uncemented humeral stem and keeled gle-noid (Aequalis AscendTM)	70.8 / 90.4	157	152.6	38.2	-	SSV& 85.5	13.2/15	1 posterior dislocation

*VAS = Visual Analogue Scale
+SST = Simple Shoulder Test
#EQ-5D score = instrument for measuring health-related quality of life (mobility, self-care, usual activities, pain / discomfort and anxiety/depression).
&Subjective Shoulder Value.

Table 2. Comparative summary of advantages and disadvantages of stemless and stemmed humeral implants		
	Stemless humeral implants	**Stemmed humeral implants**
Advantages — Stress shielding	As the fixation of the implant is at the metaphysis, there is direct load on the metaphyseal bone and no bridging of loading forces along the implant, so no stress shielding at the humeral metaphysis (may depend on the stemless metaphyseal design).	None
Bone stock	No violation of the humeral diaphysis and no stress shielding and tuberosities resorption, so preservation of local bone stock	None
Intraoperative humeral fractures	If occur, these are usually incomplete stable metaphyseal "cracks", that can be managed with suture cords.	None
Late traumatic fractures	If occur, as the stress riser is at the end of the stemless shell in the metaphysis, the healing potential of the cancellous bone in this area makes that these fractures can be treated conservatively	None
Revision surgery	The metaphyseal and diaphyseal cancellous bone is preserved, very valuable in revisions. Easy extraction of stemless humeral component. No need for humeral windows	None
Reverse for acute PHF	None	As in acute PHF there is usually fracture extension along the metaphysis, the diaphyseal fixation of stemmed implants is important for primary stability
Tendon to bone fixation of cuff remnants	As the metaphyseal bone is preserved, the stemless shell leaves space at the rim of the osteotomy, for suturing the tendon remnants directly to the bone with trans-osseous sutures.	
Primary rotational stability	The metaphyseal cancellous fixation of the tapered thin fins allows a good and immediate primary rotational stability	
Disadvantages — Stress shielding	None (Dependent on the Stemless metaphyseal design).	As the fixation of the implant is at the diaphysis, there is no loading at the metaphysis so this bone tends to disappear
Bone stock	None	Besides the stress shielding, the distal extension of stemmed implants eliminates the intramedullary diaphyseal cancellous bone
Intraoperative humeral fractures	None	When occur, these are usually located at the level of the diaphysis, so treatment would consist on a larger stem or plate osteosynthesis
Late traumatic fractures	None	As the stress riser is at the tip of the stem located in the humeral diaphysis which is cortical bone, treatment consist on revision to a longer stem or fixation with a plate
Revision surgery	None	As the fixation of the implant is diaphyseal, humeral windows or osteotomies are often needed (with often fractures)
Reverse for acute PHF	Stemless implants cannot be used for acute PHF, as in these situations there is a need for a stem as a scaffold for the tuberosities fixation	None
Tendon to bone fixation of cuff remnants	None	Diaphyseal holes should be drilled prior to stem insertion. Sutures will not slide once the stem has been inserted, so sometimes proper tissue approximation to bone is not achieved. The healing potential of tendon remnants to diaphyseal cortical bone is worse than to metaphyseal bone.
Primary rotational stability	In revision surgery when there is no enough good cancellous bone at the metaphysis or this bone is merely sclerotic, sometimes the primary stability should be achieved by adding bone graft inside the canal, or the use of a stem implant could be considered.	In very cylindric onlay stemmed implants, the primary rotational stability should be achieved by adding cement inside the intramedullary canal.

*PHF: proximal humeral fractures

TSA and 73.5% for hemiarthroplasty. The indications have been refined since then (2). The indications for glenoid replacement at that moment were: significant posterior erosion and a biconcave glenoid in the presence of a functional rotator cuff. More recently, the practice at the Reading Shoulder Unit (development centre of the CSRA)
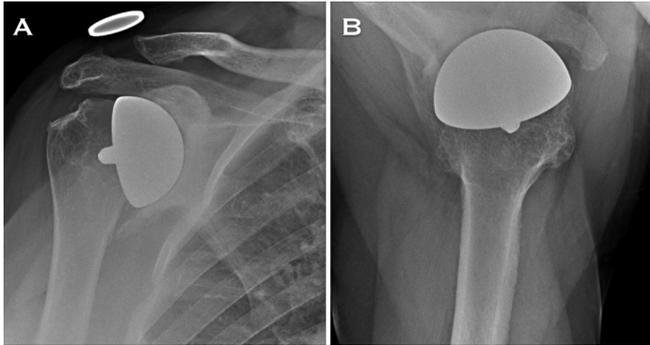

Figure 1. 1A. X-ray in the anteroposterior view of a right shoulder showing a Copeland resurfacing shoulder arthroplasty with 11 years of follow-up. It can be noticed that there is an important glenoid erosion, without clinical transcendence. See figure 2.
1B. X-ray in the axillary view of a right shoulder showing a Copeland resurfacing shoulder arthroplasty with 11 years of follow-up.

has been to perform a humeral surface arthroplasty routinely. It is ensured that the glenoid is congruent by burring away any prominences and performing a microfracture of the eroded articular surface without replacing the glenoid [Figure 3]. In fact, the results of total shoulder arthroplasty and hemiarthroplasty in one of the series described by Levy and Copeland are comparable (18). Therefore, whether to perform total shoulder arthroplasty or hemiarthroplasty remains the decision of the surgeon according to his/her own preference. If one considers that most of the long-term problems arise from the glenoid component, it seems reasonable to perform hemiarthroplasty unless there are specific indications for insertion of a glenoid component (nonconcentric erosion, saddle-shaped erosion of the glenoid) (18). Likewise, osteolysis is usually seen in association with glenoid wear and/or loosening and resultant polyethylene debris (15). These processes appear to be the primary drivers of osteolysis because this process is not commonly described in humeral hemiarthroplasty.

The thickness of the humeral component is critical for positioning of the rotator cuff with respect to its optimal length and tension. Excessive thickness can result in over-tensioning of the rotator cuff, increased contact pressures, which may lead to increased stress on the
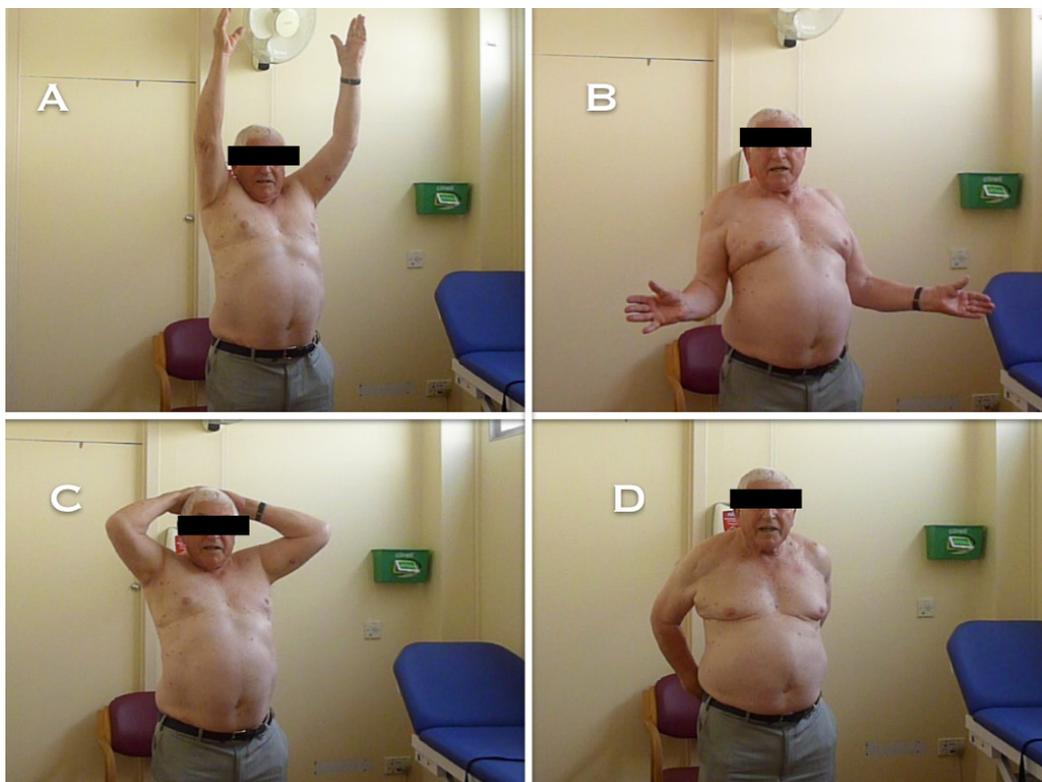

Figure 2. Clinical pictures showing the range of motion of an 83-year-old gentleman, that had a right Copeland resurfacing shoulder arthroplasty 11 years before.
2A. Elevation. 2B and 2C. External rotation. 2D. Internal rotation.

glenoid implant, accelerated glenoid loosening, failure of the rotator cuff, and loss of range of motion. Insufficient thickness can result in under-tensioning and weakness of the rotator cuff, excess translation of the humeral head, prosthetic instability, and failure of the glenoid implant, if that was the case (41). Replicating the anatomy is important to maintain correct soft-tissue tensioning and muscle-tendon balance (42). The key to correcting anatomic alignment of the humeral component is to identify the anatomic neck of the humerus. In most cases the anatomic neck can be easily identified once all osteophytes have been removed (18).

Surgical Technique

Regarding the surgical approach, we use the anterosuperior approach, as described by Neviaser and Mackenzie (43). The potential advantages of the anterosuperior approach are: a smaller scar, a shorter postoperative recovery, easier access by the rotator interval to the glenoid, and to the posterior and superior rotator cuff for reconstruction. In cases of glenohumeral osteoarthritis there is usually involvement of the acromioclavicular joint (ACJ) as well; and there may be also osteophytes on the inferior margin of the ACJ and an anterior acromial spur formation. As we anticipate that the range of motion of these patients will improve after shoulder replacement, there is a considerable chance that they will have impingement-type pain develop. Therefore, it is reasonable to decompress the subacromial space and the acromioclavicular joint at the time of operation. Using the anterosuperior approach allows us to perform decompression easily.

Regarding the exposure of the glenoid when implanting a resurfacing, it may be considered as technically demanding as the humeral head will be in front of the glenoid (23). If an extensive capsulotomy is made around the glenoid, and an adequate exposure is provided by retraction of the humeral head posteroinferiorly using a Bankart skid or Fukuda retractor, the glenoid surface could be then seen in a relatively easy manner [Figure 3]. The humeral trial component should be left in situ to protect the head of humerus from damage by subsequent
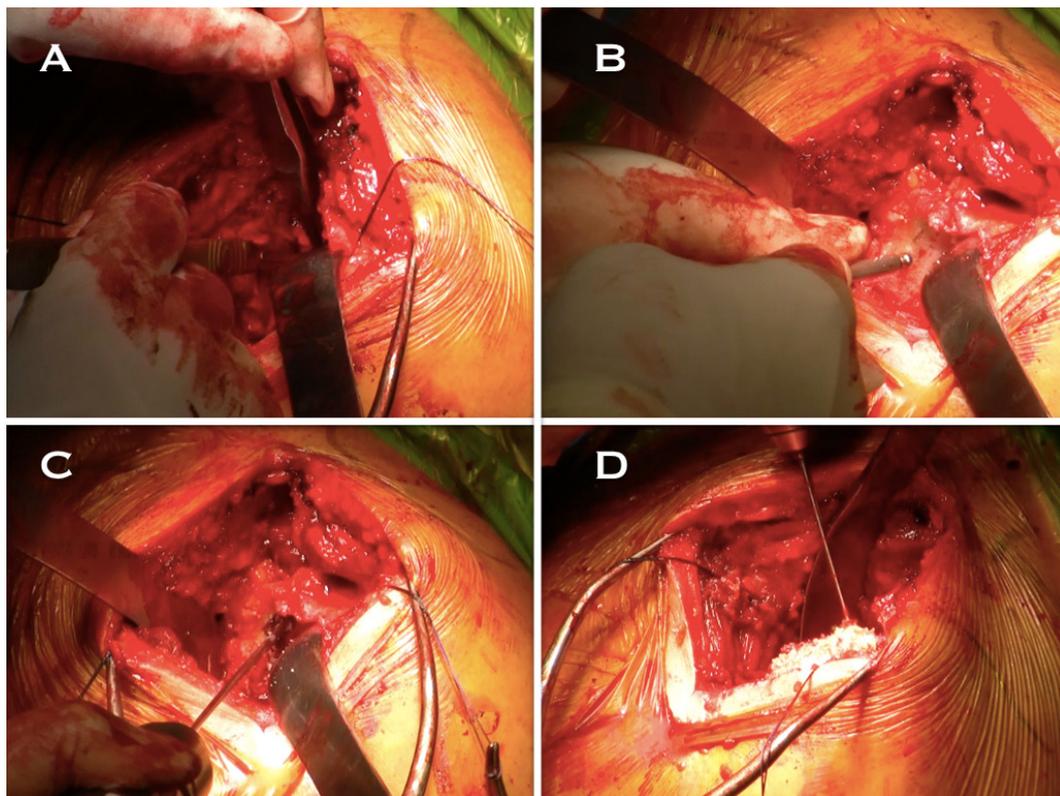

Figure 3. Intraoperative perspective of a left shoulder in which a Copeland resurfacing shoulder arthroplasty was being performed.
3A. Extensive capsulotomy is made around the glenoid to guarantee an adequate exposure of the glenoid.
3B. Adequate exposure of the glenoid is provided by retraction of the humeral head posteroinferiorly using a Bankart skid or Fukuda retractor. We ensure that the glenoid is congruent by burring away any prominences of the biconcave shape of the glenoid.
3C. Microfractures of the eroded articular surface are performed to promote the formation of fibrocartilage.
3D. Drilling of the humeral head is performed prior to the implantation of the final component to open canals that communicate the superficial cortical bone with the cancellous bone, and thus promoting the bony ingrowth.

retraction (44). In our series of stemless rTSA, we did not observe any lucent lines, loosening or subsidence of the metaphyseal stem reversed humeral component. A possible explanation is the triple tapered humeral component design that provides a good immediate press fit metaphyseal fixation with resistance to rotational torque (45) [Figure 4].

Modern implants for shoulder replacement should combine press-fit fixation with a coating that has a high surface roughness to provide a scratch fit and promote bony ingrowth (17,46). Combination of press-fit fixation, hydroxyapatite coating and impaction bone grafting are currently under the spotlight of interest (11).

Radiographic behaviour

Although clinical aseptic loosening of a resurfacing is rare, radiographic changes such as radiolucent lines, stress shielding and osteolysis, have been described in many series. The clinical relevance of these changes remains currently uncertain, but seems unrelated to the outcome (17,24). In one study that included 82 cases of glenohumeral osteoarthritis, no instances of subsidence, loosening, or revision specific to the humeral implant were reported at 2-year follow-up (47). In the prospective clinical series published in 2017 by Boileau and Walch, the radiographic assessment of stemless implants showed no signs of early migration,
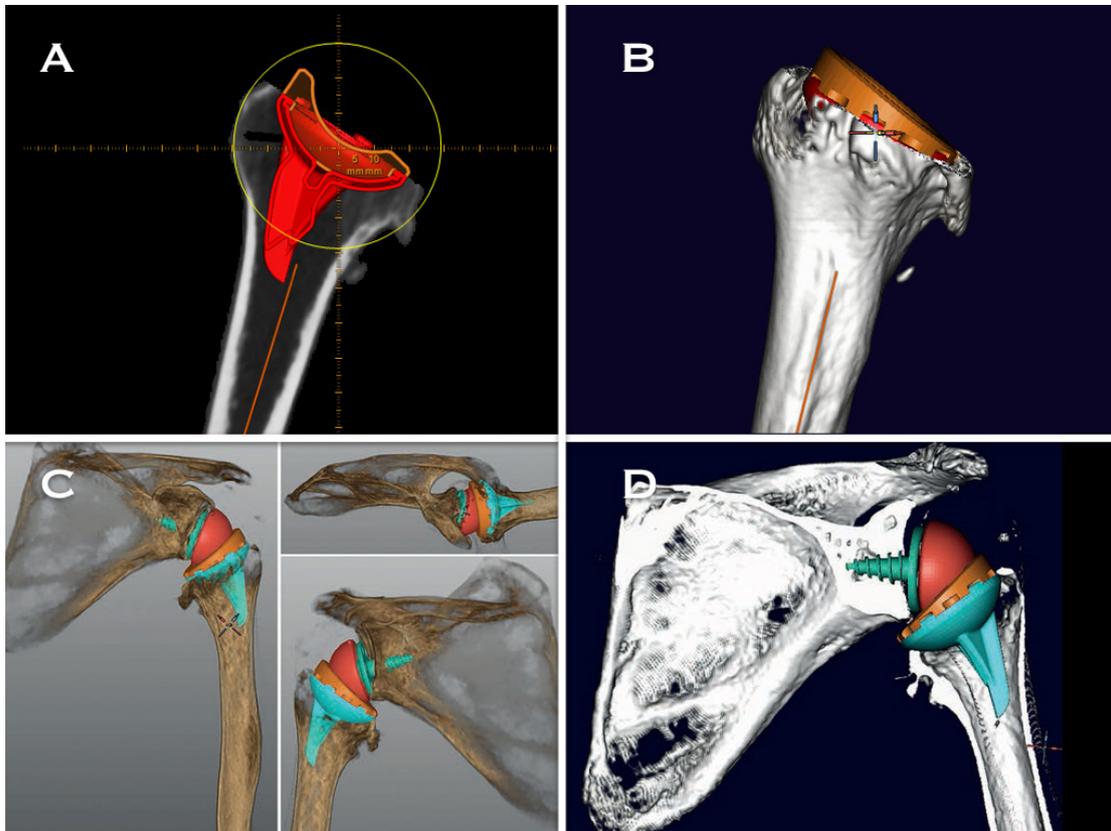

Figure 4. 4A. X-ray in anteroposterior view of a right proximal humerus, in which the inlay design and the metaphyseal fixation of the Verso can be seen in the pre-op planification. Notice that the shell of the humeral component is flush with the humeral osteotomy, and that the tip of the humeral component does not reach the proximal third of the diaphysis.

4B. In this 3D reconstruction, once the humeral liner has been placed on top of the inlay humeral shell, the initial angulation of the humeral osteotomy changes from 155 to 145 degrees, because of the medial low profile 10 degrees liner. This feature allows better active shoulder rotations; both because from the lateralization achieved, and because of the fact that the medial low profile of the liner minimizes the humeral impingement underneath the glenoid neck (glenoid notching).

4C. 3D reconstructions in which the clear space between the under surface of the glenoid neck and the medial aspect of the humeral liner can be seen. Notice also that the fixation of the glenoid baseplate is bicortical: the tip of the central peg comes out slightly from the glenoid vault.

4D. Observe the cancellous metaphyseal bone preserved around the thin fins of the stemless humeral component. These 3D images have been facilitated by IDO (Innovative Design Orthopaedics) and mediCAD (mediCAD Hectec GmbH, Altdorf Germany).

nor loosening over time at a follow-up of four years (22). However, periprosthetic radiolucent lines were observed at the upper zones in 17 of the 47 shoulders included in their study. They extended their investigation of early loosening by performing computed tomography (CT) scans on eight patients. None of the CT scans revealed signs of loosening (22).

The group of Gohlke et al. concluded in their cadaveric study that a radiolucent halo with a different magnitude is detectable on digital radiographs after implantation of a stemless humeral implant (48). The halo is directly linked to the radiation dose and appears to be an imaging phenomenon because of radiation scatter. Radiolucent halos that are imaging artefacts need to be considered in the follow-up evaluation of stemless humeral arthroplasty. Imaging halo artefacts can be reduced by lowering the tube voltage or using "prosthesis protocols" during digital radiographic examination (48). Since at the Reading shoulder unit hydroxyapatite-coated implants (Mark 3) are used, no lucent lines have been observed (18).

Regarding the stress shielding, Melis et al. found radiological signs of stress shielding in 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) (49). Contrary to stemmed implants, the stemless rTSA developed by Ofer Levy has a metaphyseal fixation rather than in the diaphysis as with stem prostheses. No lucencies around the humeral component, or resorption of bone around the humeral component, suggestive of stress shielding have been observed in the follow-up results of this implant (45).

Cementless surface replacement arthroplasty in the young population

The treatment of shoulder arthritis in the young patient remains a challenging issue. Any artificial joint, resurfacing or stemmed, may have a limited life span. The higher functional demand of the young patient may accelerate the joint wear. Young patients expect to resume all their activities, including sports, so this situation raises concerns regarding the risks of failure and need for early revision shoulder arthroplasty or even the need for a number of revision surgeries during their lifetime. The experience of shoulder arthroplasty with stemmed implants in young patients has showed worse and less predictable results than in the older patient population, with a high percentage of unsatisfactory results and a high percentage of revision surgeries (50,51). Furthermore, the involvement of younger patients in different sporting activities, including collision sports, increases the theoretical risk of sustaining a periprosthetic fracture that with a stemmed implant may occur at the humeral shaft and may be difficult to treat. The use of a resurfacing implant will diminish the risk of midshaft fractures. With resurfacing, the traumatic fractures will tend to be

metaphyseal and most can be treated conservatively or by easy conversion to stemmed implant. Because there are reduced risks of shaft fractures, the patients have less limitation on return to full sporting activities.

Between 1990 and 2003, Levy and Copeland performed 54 shoulder resurfacing in 49 patients aged younger than 50 years (12). Good long-term functional results were evidenced in 81.6% of the patients. This improvement was maintained over more than 10 years after surgery, with high patient satisfaction (8.7 out of 10). In this series, all patients, besides those that required revision arthroplasty, indicated that the resurfacing had allowed them to return to their desired activities at a satisfactory level. Most patients returned to sports activities (12).

Cementless surface replacement arthroplasty in the elderly

The implantation of a stemless shoulder prosthesis represents a reliable option for surgical treatment in elderly patients with potentially decreased bone osseous mineral density (23). Between 1993 and 2003, Levy and Copeland performed 213 resurfacing shoulder arthroplasties, of which 13.6% (29/213) were undertaken in patients over the age of 80. This group of patients was followed up for a mean of 4.5 years (2.1 to 9.3). Their mean age was 84.3 years (81 to 93). There were no peri-operative deaths or significant complications. The mean Constant score (CS) adjusted for age and gender, improved from 15.1% to 77%. In this group of patients, the risk of peri-prosthetic fracture and complications of the use of bone cement can be avoided with the cementless surface replacement arthroplasty, potentially reducing the risk of complications in this vulnerable age group (20).

Stemless reverse total shoulder arthroplasty

The first stemless RTSA was the Verso (Innovative Design Orthopaedics, London, UK; formerly Biomet, Swindon, UK), which was introduced for clinical use in 2005. The Verso was followed later by the TESS reverse shoulder. Outside of the USA, stemless RTSA implants in use are the Verso and TESS since 2005, the Nano since 2012 and the SMR stemless since 2015. The Verso has been implanted in Europe since 2005.

The Verso design has been conceived as a purely rTSA, which has a short metaphyseal humeral implant with three thin tapered fins. These are designed for impaction into the humeral metaphysis to provide immediate press-fit fixation. The implant relies on fixation in the metaphyseal cancellous bone, without the need for cortical bone fixation. Using the bone graft impaction technique, cases with osteoporosis or bone cysts can be managed with the Verso. The fins have a titanium porous and hydroxyapatite coating to allow bony ingrowth and improve the biologic fixation of the implant. The glenoid baseplate has a central tapered screw which is also hydroxyapatite-coated titanium. The humeral liners have a 10° medial inclination which provides a very low profile, thus reducing impingement between the liner and the glenoid neck, therefore reducing the

risk of scapular notching situation that allows improved rotational movements. The humeral cut is performed at an angle of 155°, and with the inclined liner the final angle results to be 145°. The liner allows the possibility to be dialled, so in this way its version can be changed according to the requirements of each case.

Levy et al. (52) also reported a series of 19 patients who have undergone staged bilateral stemless RTSA. These authors aimed to assess whether patients with bilateral stemless RTSA were compromised in activities of daily living, with particular compromise in rotational movements. Some authors have reported reduced active rotational movement following RTSA (53). It is well known that shoulder rotations are essential for activities of daily living, such as perineal and self- hygiene, eating and drinking (54). In Levy´s series, internal rotation improved from 9° to 81°, and external rotation with the arm in adduction improved from 20° to 32°. Mean postoperative patient-reported ADLEIR (Activities of Daily Living External and Internal Rotations) score was 33 out of 36 points.

These authors concluded that bilateral stemless rTSA provided predictably good functional outcomes, including rotations, and that most patients had no postoperative limitation in activities of daily living (52). The pre- and post-operative radiological and clinical status of a 46 years-old gentleman with history of psoriatic arthritis who underwent bilateral stemless reverse total shoulder arthroplasty performed with the Verso in Granollers General Hospital can be observed [Figures 5; 6].

Profile of complications

Since the introduction of modern shoulder arthroplasty, most series have demonstrated that complications related to the humeral implant, symptomatic humeral implant loosening, or the need for revision because of failure of the humeral implant are rare (16). It must be mentioned that glenoid fixation and soft-tissue factors are generally far more important than humeral implant design in ensuring durable post-operative function of the shoulder (36). Surface replacement arthroplasty may be potentially associated with problems related
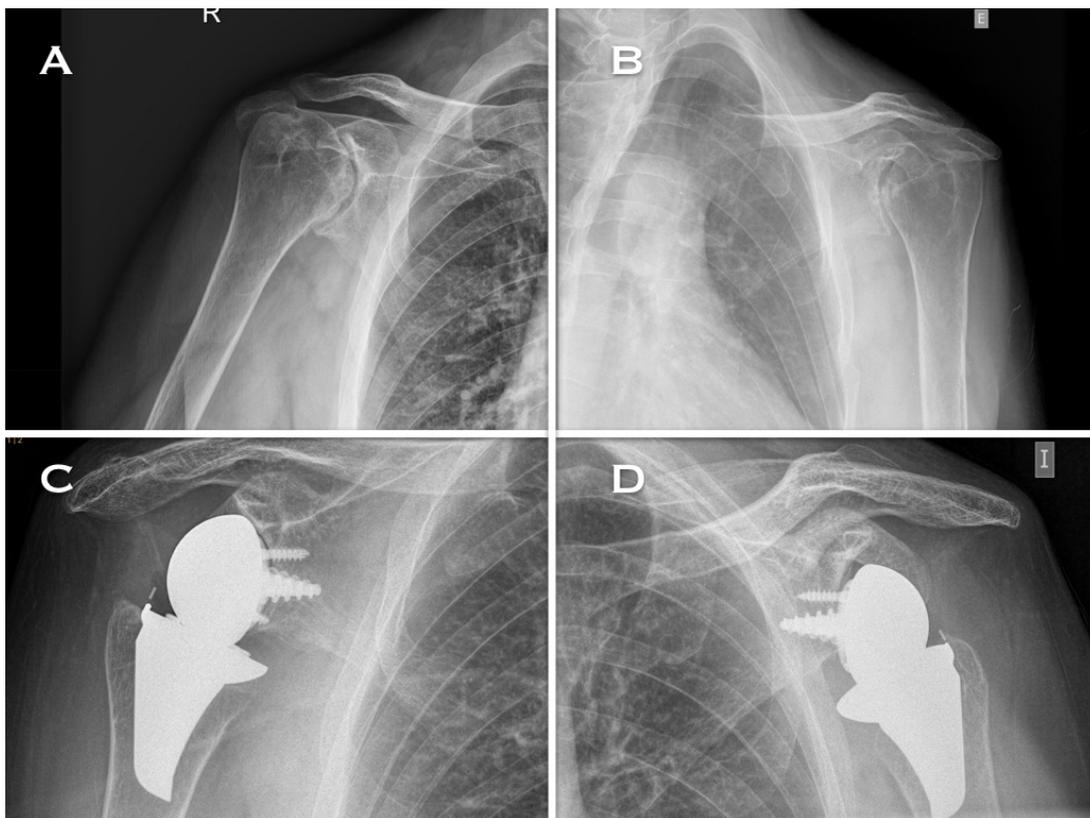

Figure 5. X-rays of both shoulders of a 46 years-old gentleman with history of psoriatic arthritis, who had undergone bilateral stemless reverse total shoulder arthroplasty with the Verso. The left shoulder was operated when the patient was 45 years-old, and the right one was operated 15 months after.
4A. Pre-operative X-ray in the anteroposterior view of his right shoulder.
4B. Pre-operative X-ray in the anteroposterior view of his left shoulder.
4C. Post-operative X-ray in the anteroposterior view of the right shoulder.
4D. Post-operative X-ray in the anteroposterior view of the left shoulder.

to an unappropriated surgical technique, such as the potential risk of "overstuffing" the humeral head component.

Some of the complications we have encountered in our stemless series have also been found in other studies, but these have been more easily dealt with because of the preservation of bone stock by use of the surface replacement. If a patient with a resurfacing fails, revision surgery can be easily achieved by either revision to a stemless reverse prosthesis, as bone stock has been maintained, no cement or stem has to be exposed and removed, and no loss of length will be encountered (19). The primary fixation must be balanced with ease of extraction (16). We believe that the humeral component does not need a stem or cement for fixation, as it is not biomechanically needed, and as it would make revision surgery significantly more complex (18).

Regarding the published series of patients (n=102) who had undergone Verso reverse total shoulder arthroplasty, two patients had an undisplaced fracture of the humeral metaphysis due to excessive bone impaction in very soft bone, and 1 glenoid rim was cracked during preparation (in a revision case) (11). These healed around the implants at 3 months with conservative treatment (11). Six patients sustained late traumatic periprosthetic fractures caused by falls. Two glenoid fractures and three proximal humeral (metaphyseal) fractures. Of the 2 glenoid fractures: One patient refused further surgery with limited outcome, and the other patient was revised with good outcome. The patients with the proximal humeral fractures were treated conservatively, and all healed with good function. One patient sustained displaced metaphyseal-diaphyseal periprosthetic fracture of the proximal humerus and had revision to a stemmed reverse prosthesis.

Revision surgery

Revision of a stemmed shoulder arthroplasty is a more demanding procedure than revision of shoulder resurfacing. Although humeral revision is relatively infrequent, efforts should be made to reduce its need, because revision of the humeral implant is associated with a high complication rate (13). The duration of the

Figure 6. Clinical pictures of the same patient presented in figure 4.
5A. Pre-operative forward flexion.
5B. Pre-operative abduction.
5C. Post-operative forward flexion (the picture was taken when the right shoulder had 18 months of follow-up, and the left one had 3 months of follow-up).
5D. Post-operative abduction. Notice that the patient showed a full elevation, even in the left shoulder that only had 3 months of follow-up.

surgical procedure has been described to be significantly longer in the context of stemmed arthroplasties, by more than 1 hour on average, and with a significantly higher need for humeral osteotomy and use of massive allograft for humeral reconstruction (13). Likewise, Natera and Levy have shown in a study in which intraoperative and postoperative complications of revision surgery from stemmed arthroplasties were compared to those of surface replacement arthroplasties, that revision of stemmed arthroplasties is a more complex procedure, and that operation time, need for humeral osteotomy, need for structural allograft, and number of intra-operative fractures were significantly higher in the stemmed arthroplasties group (13). In a different series described by Cil et al., 17% of their revised shoulders had iatrogenic intraoperative humeral fractures, 23% had cement extrusion, and 11% required early further surgery (16).

Holschen et al. described differences between stemmed and stemless primary implants in the clinical outcome after revision to rTSA (55). The postoperative CS was better in patients who were initially treated with a stemless implant (67.5 vs. 50.9). These authors concluded that conversions from stemless primary implants to rTSA lead to a superior shoulder function in comparison to stemmed primary implants. They argue that these findings illustrate the benefits of stemless primary implants, which are probably based on a less traumatic revision with a concomitant preservation of humeral bone stock (55). Besides this, they also mention that in patients that were initially treated with stemless implants and were revised because of rotator cuff insufficiency, revision surgery only represented a slightly higher surgical effort than a primary rTSA for cuff tear arthropathy (55).

Some retrospective series have shown that revision rates tend to be higher for noncemented implants than for cemented implants (17,46,56). However, substantial bias may exist within the literature regarding comparative revision rates because surgeons may be less likely to revise a cemented humeral stem than a noncemented humeral stem for similar pathology. In the series of CSRA in patients younger than 50 years old, 10 of 54 shoulders (18.5%) required revision arthroplasty. The mean time from the index arthroplasty to the revision surgery was 12 years (12). Besides 1 shoulder with traumatic periprosthetic fracture at 1 year after the resurfacing, the rest were clinically alright after a long period that spans 8 to 23 years after the index resurfacing (12).

Survival of shoulder resurfacing

The implant survival free of revision with the Kaplan-Meier survival curve for all patients aged 50 years or younger receiving shoulder resurfacing arthroplasty have been previously assessed (12). The estimated revision-free survival rate for humeral head resurfacing (hemi) was 97% at 5 years, 97% at 11 years, 91% at 14 years, and 85% at 22 years (12). The estimated revision-free survival rate for TSA was 100% at 5 years, 71% at 11 years, 71% at 14 years, and 61% at

22 years(12). Tomas et al. described their survival analysis in shoulders treated with CSRA, and it showed no variance from historical standards for shoulder replacement (21). With revision of the implant used as the endpoint, the 5-year survival rate was 98.2%. This fell to 91.9% when reoperation for any reason was taken as the endpoint (21).

Traumatic fractures

The risk of periprosthetic fractures due to falls exists with any type of prosthesis. Nearly three fourths of all proximal humerus fractures occur in patients older than 60 years, and they generally occur as a result of low-energy trauma such as a fall from standing height (57). The risk of late periprosthetic fractures is higher due to the presence of the metal implant as stress riser (58). Stemmed implants create a stress riser effect at the tip of the stem in the midshaft of the humerus (59). If a diaphyseal stem prosthesis is used, the periprosthetic fractures tends to occur at the humeral shaft where the metal–bone interface stress riser exists. With a short metaphyseal stem prosthesis the stress riser remains in the metaphysis and the fracture will be metaphyseal and therefore applicable for conservative treatment, because this zone has a better potential to heal (11). While late traumatic periprosthetic humeral fracture in diaphyseal stem prostheses has to be revised in the majority of the cases and has a negative effect on the results (9). In the series of rTSA with a cementless short metaphyseal humeral implant without a stem, most of these fractures were metaphyseal and were treated conservatively with good clinical and radiological outcomes (11). In a paper published by Anderson et al, there were 36 periprosthetic fractures treated surgically by either open reduction and internal fixation or revision arthroplasty. They concluded that: "Periprosthetic fracture around a humeral stem implant is a difficult clinical problem involving complex decision-making… Complications were frequent, and a reoperation was required in 19 % of the patients. More than half of the patients in our study had a loose humeral component that required revision."(58).

Overview

Stemless humeral prosthesis might represent an interesting and reliable option to consider in primary shoulder arthroplasties. It is currently clear that, biomechanically, stems are only required in the context of humeral fractures with diaphyseal extension, or wide tumoral resections. The clinical outcomes of stemless implants have been shown to be comparable or better than those of traditional stemmed implants. In case of failure of the index procedure, stemless implants would diminish the potential complications that may be related to the need to remove a well-fixed stem. Likewise, nowadys it seems clear that the clinical outcomes obtained after a revision shoulder arthroplasty performed in the context of bone preserving implants, may be more encouraging since the status of the bone stock and the tissues overall is less damaged. When

treating shoulder arthritis, the surgeon must always consider "the patients' journey through life", and think about the possibility of future procedures and further operations. Stemless bone-preserving implants will help keeping future options open.

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