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ORIGINAL ARTICLE

Postoperative radiographic findings of an uncemented convertible short stem for anatomic and reverse shoulder arthroplasty

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Background: Several short-stemmed press-fit humeral components have been developed in recent years for anatomic total shoulder arthroplasty (TSA) as well as reverse shoulder arthroplasty (RSA). Varying radiographic outcomes have been reported, with some studies reporting concerning rates of aseptic loosening. This study analyzed the radiographic findings of a press-fit convertible short-stemmed humeral component in both TSA and RSA.
Methods: There were 150 anatomic TSAs (group 1) and 77 RSAs (group 2) analyzed radiographically at a minimum follow-up of 2 years postoperatively. Plain radiographs were reviewed for stem loosening, alignment, signs of stress shielding, and the filling ratio.
Results: At final follow-up, 49% of group 1 and 65% of group 2 had no evidence for radiographic changes. In those with radiographic changes, low bone adaptions were found in 83% and high adaptions in 17% in both groups. Larger stem sizes with higher filling ratios were associated with high radiographic adaptions in both groups ($P = .02$). The overall filling ratios were higher in group 2 ($P = .002$). Cortical contact of the stem led to higher bone adaptions ($P = .014$).
Conclusions: The short humeral component analyzed in this study showed encouraging survival rates without aseptic loosening. Radiographic changes are associated with a higher filling ratio and cortical contact of the stem. Surgeons should aim to achieve fixation with the minimal required canal filling to minimize radiographic changes with the uncemented humeral component used in this study.
Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Shoulder arthroplasty; humeral stem; humeral component; reverse arthroplasty; arthroplasty; shoulder replacement; shoulder

The Hopital Privé Jean Mermoz and the Centre Orthopédique Santy Ethical Committee Institutional Review Board approved this study (Ref. Study 2016-20).

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Anatomic total shoulder arthroplasty (TSA) and reverse shoulder arthroplasty (RSA) are effective treatment options for degenerative diseases of the glenohumeral joint.[3,19,22] For both implant concepts, different fixation methods were introduced for the glenoid component and for the humeral stem. Humeral components with a stem length >100 mm were traditionally implanted with cement fixation. Excellent long-term results have been reported for TSA and RSA with this technique, with survival rates >90% at 10 years.[2,9,16,21]

Cementing the humeral component has several disadvantages, however. Cementing increases surgical time and can lead to thromboembolism. Moreover, in the case of revision, removal of a well-fixed cemented stem is difficult, often requiring humeral osteotomy, and the risk of iatrogenic fracture and proximal humeral bone loss is increased. Because of these issues, press-fit humeral components were introduced.[15,18,21,24,27,28] Comfort with a press-fit approach led to the subsequent development of short stem designs (length, 50-100 mm) designed for metaphyseal fixation as opposed to standard-length stems, which often achieved diaphyseal fixation.[1,7,13,23,25] Currently, these bone-preserving uncemented short stems are frequently used for anatomic TSA as well as RSA.

Several press-fit short stem humeral components with different designs are currently commercially available. One of these stems, the Ascend Flex (Wright Medical, Memphis, TN, USA), has a curved shape with a collarless design that is convertible between anatomic TSA and RSA. The first generation of this stem (Ascend) was nonconvertible and associated with high rates of stress shielding and a loosening rate of approximately 8%[4] in anatomic TSA. This led to the addition of proximal porous coating in the second generation (Ascend Flex) convertible design.

Reports with this design modification have been more encouraging.[10,17] However, both studies were limited by small numbers of TSAs, and neither study evaluated the stem in the setting of RSA. The aim of this study was therefore to evaluate the short-term radiographic results of this press-fit short stem in anatomic TSA and RSA. We hypothesized that the radiographic findings would not differ between the 2 configurations.

Materials and methods

A retrospective analysis of radiographic data was performed in patients who underwent anatomic TSA (group 1) or RSA (group 2) at 2 specialized shoulder centers (4 surgeons) between 2011 and 2014. Inclusion criteria were a (1) minimum follow-up of 2 years, (2) complete radiographic data immediately after surgery and at final follow-up, (3) primary glenohumeral osteoarthritis without concomitant full-thickness rotator cuff tears in patients who underwent anatomic TSA, (4) cuff tear arthropathy or osteoarthritis of the glenohumeral joint in combination with full-thickness rotator cuff tears or massive glenoid erosion in patients who underwent reverse TSA, and (5) treatment with the same Ascend Flex uncemented and convertible short stem.

In group 1, 173 TSAs met the study criteria; however, 23 shoulders (13%) were excluded due to lost follow-up (n = 14) or inadequate radiographs (n = 9), leaving 150 TSAs (86.7%) in 146 patients available for the final analysis. In group 2, 95 RSAs met the study criteria; however, 18 (19%) were excluded due to lost follow-up (n = 10) or inadequate radiographs (n = 8), leaving 77 RSAs (81.1%) available for analysis.

Patients were a mean age of 68 years (range, 30-85 years) in group 1 and 72 years (range, 50-91 years) in group 2. In group 1, the right shoulder was operated on in 81 patients and the left in 69. In group 2, the right shoulder was operated in 51 patients and the left in 26.

The overall cohort included in this study consisted of 150 anatomic TSAs (146 patients) with a mean follow-up of 32 months (range, 24-58; median, 27 months) and 77 RSAs (72 patients) with a mean follow-up of 28 months (range, 24-48; median, 27 months).

Implant

The stem used in this study is available in short and standard lengths, with 8 different sizes each. In this study, only the short stem was used, which ranges in length from 66 to 94 mm based on diameter. The stem is made of titanium and has a proximal porous coating (plasma spray) on the metaphyseal section for bone ingrowth. For anatomic TSA, 3 different inclination angles of the stem are available (127.5°, 132.5°, and 137.5°). Humeral heads varying in size and made of cobalt-chrome can be used with an offset of 1.5 mm or 3.5 mm. For RSA, a stem with an inclination of 132.5° is used with a humeral tray available in 2 different offsets (1.5 mm and 3.5 mm). An asymmetric polyethylene insert with 12.5° of inclination is connected to the tray, resulting in a humeral inclination angle of 145°.

Surgical technique

A deltopectoral approach was used in all patients. The subscapularis was incised and released, and a tendon-to-tendon repair was done afterward with 5 to 6 nonabsorbable sutures. The humeral head was resected with a freehand technique after removal of osteophytes and identification of the anatomic neck. The glenoid was exposed by using 4 retractors, and the guide pin was placed centrally for anatomic TSA and more inferior for RSA. Reaming was performed over the guide pin, and the subchondral bone layer was preserved as good as possible in each case.

Anatomic glenoid components were cemented, and the reverse arthroplasty baseplate was fixed uncemented. After the glenoid component was placed, the humeral canal was opened and sized with canal finders. Then, the humeral canal was progressively broached with a polished device to compact the cancellous bone for the final implant. These compactors have the same shape of the humeral implant and were used to test rotational stability after full seating. The definitive implant with a 2-mm press-fit was then impacted into place, followed by placement of the humeral component. Preoperative planning of the stem size was not done at this time, and a C-arm was not used to control implant position. During the study period, 6 patients planned for press-fit fixation required cement fixation due to insufficient primary stability. These patients were not included in this study. In case of RSA the humeral tray was positioned slightly below the tip of the greater tuberosity to avoid excessive lengthening of the arm. After placing the liner and reduction, the arm was moved and checked for stability and correct tension. A drain was placed, and the wound was closed.

Radiographic examination

Scaled and digital radiographs of the affected shoulders were obtained immediately after arthroplasty and at final follow-up in at least 3 different rotations. True anterior-posterior views of the glenohumeral joint were obtained under fluoroscopic control. Radiographic examination was performed according to the method introduced by Schnetzke et al.[25] The stem inclination relative to the humeral shaft axis was measured in degrees. The filling ratio of the humeral shaft was measured at the level of the metaphysis and diaphysis (Figs. 1 and 2). The inclination was defined as neutral if the angle of the stem relative to the humeral canal was ±5°. The inclination was defined as valgus if the angle was >5° and as varus in cases with an angle of <5°.

Bone remodeling was analyzed according to Schnetzke et al[25] in 5 zones around the humeral stem defined as follows: lateral-proximal zone, L1; lateral-distal zone, L2; medial-proximal zone, M1; medial-distal zone, M2; and zone under the tip of the stem, US. In each zone, the presence or absence of the following findings were recorded: (1) condensation lines, (2) cortical bone resorption or osteopenia (CNO), and, (3) spot welds. Remodeling was classified as absent if 0 to 1 findings were observed, as mild in cases of 2 to 3 findings, as moderate in cases with 4 to 6 findings, and as severe if changes in each of the 5 zones or changes occurred, or both. For the purposes of analysis, findings were categorized into low (no or mild findings) or high (moderate or severe) adaptions.

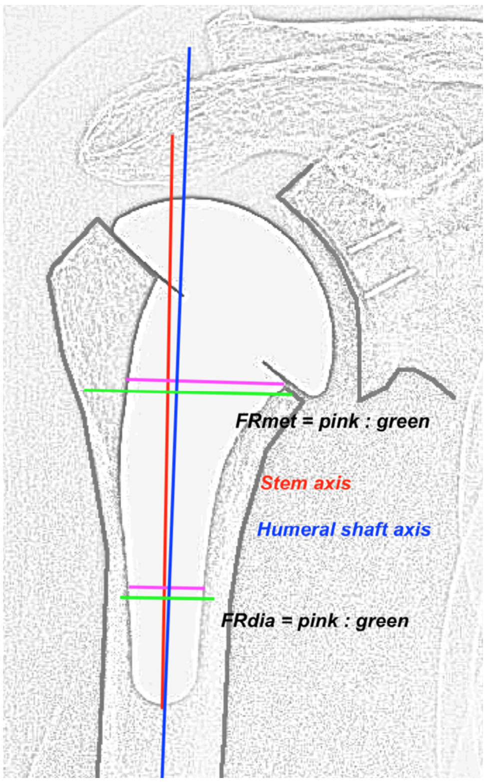

Figure 1 The inclination angle for anatomic shoulder arthroplasty was measured between the shaft axis (*blue line*) and the stem axis (*red line*). Filling ratios were measured at the metaphysis (*FRmet*), with a perpendicular line to the shaft axis starting at the medial-inferior border of the humeral head, or at the diaphysis (*FRdia*), with a perpendicular line to the shaft axis intersecting at the distal third of the humeral stem. The quotient between the *pink* and the *green line* is the filling ratio at each level.

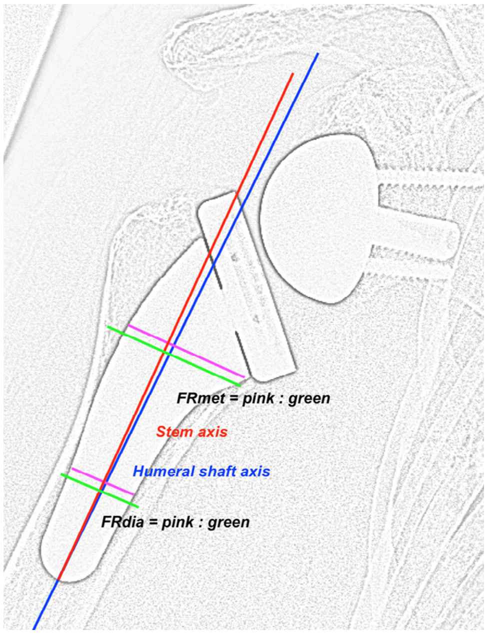

Figure 2 The inclination angle for reverse shoulder arthroplasty was measured between the shaft axis (*blue line*) and the stem axis (*red line*). Filling ratios were measured at the metaphysis (*FRmet*) with a perpendicular line to the shaft axis starting at the medial-inferior border of the humeral metallic tray—or at the diaphysis (*FRdia*) with a perpendicular line to the shaft axis intersecting at the distal third of the humeral stem. The quotient between the *pink* and the *green line* is the filling ratio at each level.

Cortical thickness was measured according to the method of Mather et al.[14] This study has shown that a cortical thickness of 6 mm is a potential threshold value for predicting osteoporosis. The influence of cortical thickness as well as patient age, sex, and hand dominance were analyzed regarding the occurrence of radiographic bone remodeling.

Analysis was done by 2 independent examiners (P.R. and M.S.). In the event of disagreement, the radiograph was discussed and a consensus was reached. The intraobserver and interobserver agreement was calculated. Images were analyzed using the picture archiving and communication system Image Viewer (Kodak, New York, NY, USA).

Statistics

Means and standard deviations (SD) were calculated for continuous variables. Differences between preoperative and postoperative continuous data were analyzed using the Wilcoxon signed rank test. The Mann-Whitney *U* test was used to compare the 2 groups of patients. For the analysis of contingency tables, the χ^2 test was used. The level of significance was set at $P < .05$. Interobserver agreement was calculated with the Cohen κ, and agreement strength was inferred in accordance with the recommendations of Landis and Koch.

Results

Interobserver variability of the radiographic analysis was almost perfect between the 2 examiners (κ = 0.894).

Group 1

Stem inclination was neutral in 73% (n = 109) of shoulders, in valgus position in 19% (n = 29), and in varus position in 8% (n = 12).

At final follow-up, no radiographic changes were detected in 49% of anatomic shoulder replacements (n = 73). Mild changes were found in 34% (n = 51), moderate in 16% (n = 24), and severe in 1% (n = 2). Therefore, low bone adaptions were observed in 83% (n = 124) and high adaptions in 17% (n = 26). The most frequent findings in the 5 regions were: L1, CNO; L2, spot welds; M1, CNO; M2, spot welds; US, condensation lines (Fig. 3). The radiographic findings are summarized in Table I.

The filling ratio influenced the occurrence of radiographic changes. In the metaphysis, patients with low adaptions had a filling ratio of 0.57 vs. 0.64 in patients with high adaptions ($P < .001$). Similarly, the filling ratio in the diaphysis was 0.73 in patients with low adaptions vs. 0.80 in patients with high adaptions ($P = .003$). Moreover, high adaptations were more common in patients with cortical contact of the stem at the diaphysis (odds ratio, 3.4; $P = .014$; Table II). The relative risk for "high bone adaptations" was 4.1-fold increased with a diaphyseal filling ratio of ≥0.7 ($P = .006$; Table III and Fig. 4).

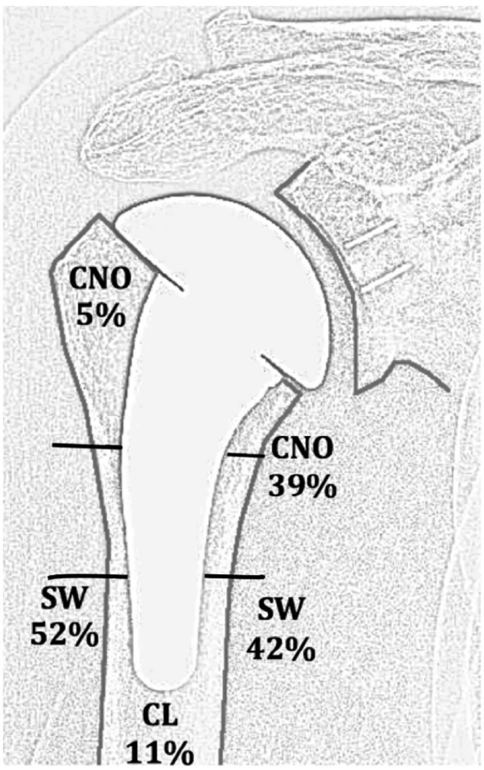

Figure 3 Most frequent radiographic changes at the proximal humerus at final follow-up in percentages in group 1 (anatomic total shoulder arthroplasty). *CNO*, cortical bone narrowing and osteopenia; *SW*, spot welds; *CL*, condensation lines.

Table I Distribution of radiographic changes in patients with anatomic shoulder arthroplasty in the 5 zones at final follow-up

Final FU	L1	L2	M1	M2	US
No changes	143 (95)	68 (45)	91 (61)	76 (51)	133 (89)
Spot welds	0	78 (52)	1 (1)	63 (42)	0
CNO	7 (5)	13 (9)	58 (39)	19 (13)	0
CL	0	0	0	0	17 (11)

FU, follow-up; *YL1*, lateral-proximal zone; *L2*, lateral-distal zone; *M1*, medial-proximal zone; *M2*, medial-distal zone; *US*, zone under the tip of the stem; *CNO*, cortical bone narrowing and osteopenia; *CL*, condensation lines.
Data are presented as number (%).

Table II Influence of cortical contact on the occurrence of radiographic changes

Variable	Radiographic changes		
	Low	High	Total
No cortical contact	84	11	95
Cortical contact	40	15	55
Total	124	26	150

$P = .014$ by χ^2 test.

Table III The relative risk for "high bone adaptations" was 4.1-fold increased with a diaphyseal filling ratio of ≥0.7 ($P = .006$)

Variable	High bone adaptation		
	Yes	No	Total
Filling ratio <0.7, No.	3	49	52
Filling ratio ≥0.7, No.	23	75	98
Total, No.	26	124	150

Female sex, patient age >65 years, and cortex thickness <6 mm were associated with high bone adaptions ($P = .024$). Hand dominance was not associated with high bone adaptions ($P = .1$).

Group 2

Stem inclination was neutral in 84% (n = 65) of RSAs, in valgus position in 12% (n = 9), and in varus position in 4% (n = 3).

At final follow-up, no radiographic changes were detected in 65% (n = 50) of RSAs. Mild changes were found in 18% (n = 14), moderate in 12% (n = 9), and severe in 5% (n = 4). Therefore, low bone adaptions were observed in 83% (n = 64) of RSAs and high adaptions in 17% (n = 13). The

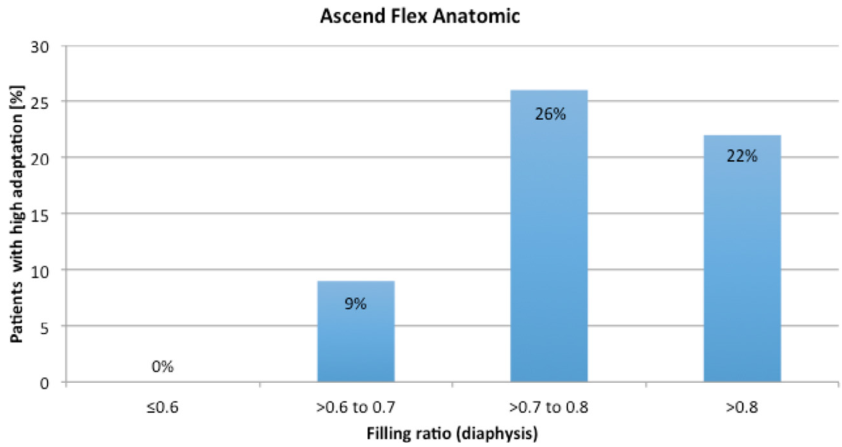

Figure 4 Distribution of patients (%) with high bone adaptions in relation to the diaphyseal filling ratio in group 1 (anatomic total shoulder arthroplasty).

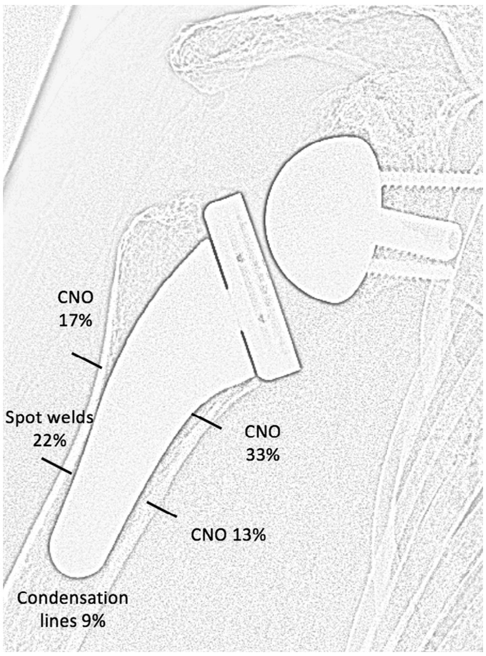

Figure 5 Most frequent radiographic changes at the proximal humerus at final follow-up in percentages in group 2 (reverse shoulder arthroplasty). *CNO*, cortical bone narrowing and osteopenia; *SW*, spot welds; *CL*, condensation lines.

Table IV Distribution of radiographic changes in patients with reverse shoulder replacement in the 5 zones at final follow-up

Final FU	L1	L2	M1	M2	US
No changes	63 (82)	49 (64)	51 (66)	58 (75)	70 (91)
CNO	13 (17)	9 (12)	25 (33)	10 (13)	0
Spot welds	1 (1)	17 (22)	0	6 (8)	0
CL	0	4 (5)	1 (1)	3 (4)	7 (9)

FU, follow- up; *YL1*, lateral-proximal zone; *L2*, lateral-distal zone; *M1*, medial-proximal zone; *M2*, medial-distal zone; *US*, zone under the tip of the stem; *CNO*, cortical bone narrowing and osteopenia; *CL*, condensation lines.
Data are presented as number (%).

Table V Influence of cortical contact on the occurrence of radiographic changes in reverse arthroplasty

Variable	Radiographic changes		
	Low	High	Total
No cortical contact	47	5	52
Cortical contact	17	8	25
Total	64	13	77

$P = .014$ by χ^2 test.

most frequent findings in the 5 regions were L1, CNO; L2, spot welds; M1, CNO; M2, spot welds; US , condensation lines (Fig. 5). Distribution of radiographic findings are provided in Table IV. Stem inclination was neutral in 84% (n = 65) of RSAs, in valgus position in 12% (n = 9), and in varus position in 4% (n = 3).

As in group 1, the filling ratio in group 2 influenced the occurrence of radiographic changes. In the metaphysis, patients with low adaptions had a filling ratio of 0.68 vs. 0.74 in patients with high adaptions ($P = .017$). Similarly, the filling ratio in the diaphysis was 0.77 in patients with low adaptions vs. 0.85 in patients with high adaptions ($P = .001$). Cortical contact of the stem led more frequently to high adaptions ($P = .014$; Table V). The relative risk for "high bone adaptations" was 7.0-fold increased with a diaphyseal filling ratio of ≥0.8 ($P = .001$; Table VI, Fig. 6).

In group 2, only female sex was associated with high bone adaptions ($P = .018$) and hand dominance, patients age, and cortical thickness were not ($P = .14$).

Complications and revisions

The overall complication rate in group 1 was 3.3%. One patient had a neurapraxia of the axillary nerve that resolved completely

Table VI The relative risk for "high bone adaptations" was 7.0 fold increased with a diaphyseal filling ratio of ≥0.8 ($P = .001$)

Variable	High bone adaptation		
	Yes	No	Total
Filling ratio <0.8	2	41	43
Filling ratio ≥0.8	11	23	34
Total	13	64	77

after 6 months without further intervention. Another patient reported subjective instability due to postoperative subscapularis failure; no further treatment was performed. An infection in 1 patient was treated with débridement and implant retention. This patient had a radial nerve palsy after the second procedure that resolved completely after 2 years. One patient developed secondary rotator cuff deficiency with cranial migration of the proximal humerus. This patient underwent revision to RSA without stem removal.

The overall complication rate in group 2 was 7.8%. There were 2 infections that required component revision. In addition, early infection with *Cutibacterium* (formerly *Propionibacterium*) *acnes* occurred in 2 patients at 4 and 6 weeks postoperatively. Both patients underwent revision surgery with débridement and change of the polyethylene liner and the glenosphere. A dislocation in 1 patient 5 months postoperatively was managed with revision with a thicker polyethylene liner. A type 2 acromial stress fracture, according to Levy et al,[12] occurred in 1 patient and was treated nonoperatively.

Discussion

Anatomic TSA and RSA have both become safe, effective, and reproducible procedures with good midterm to long-term results. As such, the annual number of these procedures continues to increase. Traditionally, standard-length stems >100 mm in length were used in a cemented or uncemented fashion. However, short press-fit stems have been developed with the goal of preserving bone and facilitating revision by ease of extraction or by a convertible design.

Anatomic shoulder replacement

Radiographic changes around humeral components are not uncommon and have been reported in the past. For example, Nagels et al[18] reported a series of 64 uncemented uncoated humeral head replacements at a mean follow-up of 5 years. The main indication for arthroplasty in their study was rheumatoid arthritis. Significant signs of stress shielding were observed in 6 shoulders (9%), and complete resorption of proximal-lateral region of the humerus was found in another 3. Similar to our findings, stress shielding was more frequently found in shoulders with a high filling ratio (0.57 vs. 0.48; $P < .013$).

Another study, by Verbogt et al,[28] published the results of the uncemented Neer II humeral component (3M, St. Paul, MN, USA). Although no component revision occurred, one has to mention that 5 of 37 components had tilted, and 19% were judged to be at risk for loosening.

Raiss et al[21] analyzed a large series of 395 cemented and uncemented stems. The uncemented stem used in their study was designed with a distal taper and a porous coating at the metaphysis for bone ingrowth (Tornier Inc., Edina, MN, USA). Of the 103 shoulders treated with an uncemented stem, signs of stress shielding were frequently observed, with internal bone remodeling in 63%, spot welds in 80%, and condensation lines in 83%. Stress shielding was not observed in the cemented humeral components.

Due to these above-mentioned theoretical advantages of uncemented short stems, new designs were introduced in the past. The first-generation Ascend monolithic stem was designed without a porous coating at the metaphyseal portion. Schnetzke et al[25] analyzed this component in 52 patients at a mean follow-up of 32 months. High radiographic bone adaptions were seen in 52% of patients with cortical thinning, osteopenia in 83%, and spot welds in 79%. Worse results were found by Casagrande et al[4] using the same stem design, with high rates of radiolucencies around the stem. Lucent lines were present in 71%, and 8% of these stems were judged to be at risk for loosening. Another 6 of 73 shoulders (8%) underwent revision surgery secondary to humeral component loosening.

These high amounts of radiographic changes and failures led to a change of the component design with a porous coating at the metaphysis. The porous coating was probably added to change the stress distribution at the proximal humerus to lead the stress coming from the humeral head more closely to the normal anatomy into the humeral metaphysis and stem. It seems that this implant modification reduced the percentage of radiographic changes, because high bone adaptions in our study decreased to 17% during the same follow-up period (32 months) compared with 52% in the study of Schnetzke et al.[25] However, only 49% of the humeral components had no signs of bone remodeling in our study. Moreover, the follow-up in this study is very short. Although the radiographic results are better compared with the aforementioned design, whether those findings will progress in the future, leading to possible implant loosening and failure, is not clear. In the short-term follow-up of this series, however, no stem loosened or required revision surgery secondary to stem problems.

Morwood et al[17] investigated both Ascend stem types with 34 shoulders in each group and found that the risk for aseptic loosening and the occurrence of radiolucent lines was substantially less frequent with the newer stem design (loosening: 3% vs. 21%; lucent lines: 21% vs. 44%).

Romeo et al[23] analyzed another short stem (Apex; Arthrex Inc., Naples, FL, USA) with a straight design and an additional collar. Of the 64 shoulders, 9% were deemed at risk for loosening after a mean of 25 months of follow-up, but no gross loosening was detected.

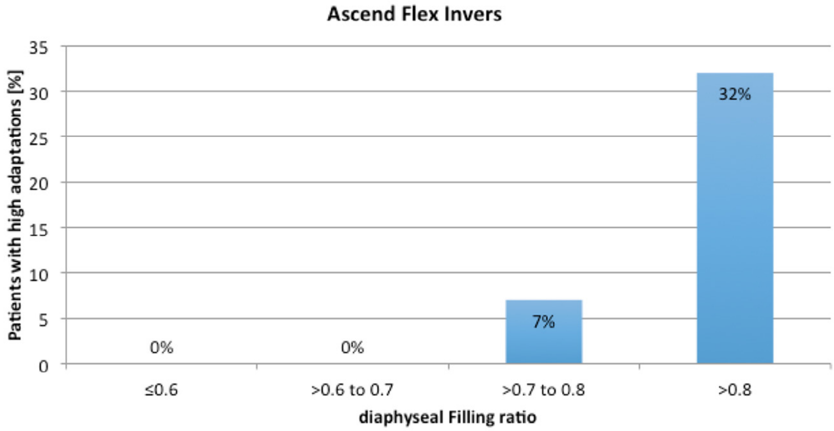

Figure 6 Distribution of patients (%) with high bone adaption in relation to the diaphyseal filling ratio in group 2 (reverse shoulder arthroplasty).

More recently, Denard et al[5] compared the short-term radiographic findings of 2 different stem designs (Apex vs. Ascend and Ascend Flex) in 77 patients. They found less favorable results for the Ascend stems. The amount of high bone adaptions was significantly higher in the Ascend group than in the Apex group (62% vs. 23%), although the canal fill index was higher in the Apex group. This could lead to the conclusion that stem design seems to be more important than the size of the stem that is press-fit into the humeral canal. In their study, the 2 different Ascend stem types (Monolithic and Flex) were analyzed together, probably leading to the above-mentioned favorable findings of the Apex stem. The 17% incidence of high bone adaptions in the current study seem to be comparable to those in the Denard et al[5] study.

Reverse shoulder replacement

As for anatomic shoulder replacement, radiographic changes around humeral components are not uncommon in reverse arthroplasty. Several studies have demonstrated that uncemented humeral components provide similar clinical and radiographic outcomes compared with cemented components in RSA.[6,11,20,29]

Harmsen and Norris[8] reported a series of 232 cementless RSAs after a minimum follow-up of 2 years. The implant used in their study had a diaphyseal fixation, hydroxyapatite coating, and a smooth metaphyseal part (Tornier Inc.). Signs of stress shielding were observed in more than 97% of shoulders, and complications occurred in 15%. Aseptic loosening was not observed.

Gilot et al[6] found in a series of 115 uncemented Equinoxe stems (Exatech Inc., Gainesville, FL, USA) no radiographic loosening at 40 months postoperatively, and radiolucent lines were detected in 26%.

Melis et al[16] investigated a cohort of patients who underwent RSA with cemented or uncemented stems (Delta III; DePuy Int. Ltd., Leeds, UK). Overall, radiographic signs of stress shielding were significantly higher in the uncemented group. A high filling ratio was associated with increasing numbers of condensation lines and spot welds.

As with anatomic arthroplasty, short and uncemented stems can also be used for reverse shoulder replacement. In 2014, Giuseffi et al[7] reported a series of 44 shoulders treated with a short stem (83 mm length; Biomet Comprehensive System, Warsaw, IN, USA) after 27 months of follow-up. They noted no implant failure, and 30% of shoulders demonstrated bone remodeling at the proximal part of the humerus. Complete resorption of both tuberosities was observed in 1 shoulder.

Atoun et al[1] analyzed a short stem with metaphyseal fixation (Verso; Biomet) in 31 shoulders at a minimum follow-up of 24 months. The implant has fins and a porous hydroxyapatite coating. The authors reported no subsidence or radiolucent lines. However, signs of stress shielding were not analyzed in detail. The same study group published another series[13] of the same implant with 98 shoulders included with a follow-up of between 2 and 7 years. As in their first report, they found no signs of loosening or radiolucent lines, and no signs of stress shielding were observed.

One study by Schnetzke et al[26] reported the radiographic outcome of the Ascend Flex stem in both anatomic TSA and RSA. They monitored 53 shoulders (29 anatomic and 24 reverse replacements) for a mean of 25 months. Comparable to our study, the number of high bone adaptions was relatively low, with 26% in the anatomic group and 10% in the reverse group. As in the present investigation, bone adaptions were associated with a higher filling ratio. In theory, the forces and stress on the proximal humerus are different for anatomic and reverse arthroplasty because share forces may be frequent in anatomic replacement and compression forces in reverse arthroplasty. Interestingly, the amount of high bone adaptions in the current study was similar in both groups, at 17% overall. Although women had a higher risk in both groups, osteoporosis, as defined by Mather et al,[14] and patient age were only associated with high bone changes in anatomic TSA. Based on these findings, the implant configuration (anatomic or reverse) seems to be less important than the filling ratio.

Surgical technique therefore seems to be crucial to minimize radiographic bone adaptions when using this uncemented humeral component. Surgeons should try to place the stem perpendicular into the humeral canal (to avoid cortical contact) and should avoid oversizing, because we have shown that a filling ratio of ≥0.7 for anatomic arthroplasty and ≥0.8 for reverse arthroplasty increases the rate of high bone adaptions dramatically. These findings may have a clinical effect on preoperative planning because the maximum stem size could be calculated by 3-dimensional planning tools.

We recommend to start broaching with the smallest size available and to check the rotational stability of each broach. Appropriate stability is achieved if the broach can be rotated together with the proximal humerus without motion between the trial component and the bone, but the temptation to increase the size and "fill the canal" should be avoided. If cortical contact is observed upon broaching (as in the setting of osteoporosis with poor-quality metaphyseal bone), it may be advisable to cement a polished stem rather than press-fit a stem that fills the entire canal. This was done in our series 6 times to avoid a high canal fill index and should be kept in mind as a viable alternative to uncemented fixation. In addition, preoperative templating or 3-dimensional planning could potentially be useful for choosing the appropriate stem size, but this has not been analyzed yet.

This study has some limitations. First, this is a retrospective study, and only 1 stem type was analyzed. Moreover, 4 surgeons from 2 centers participated in this study, and surgical techniques and radiographs may have differed slightly.

The results are short-term, and longer follow-up is required to evaluate how the radiographic appearance changes over time related to loosening. For this short follow-up period, the percentage of patients lost for follow-up or excluded because of inadequate radiographs was rather high. This may reflect a selection bias.

In addition, we did not evaluate functional outcomes scores or range of motion and correlate these with adaptive changes. Our goal was simply to evaluate the radiographic findings of the particular implant.

Conclusion

The humeral component analyzed in this study showed no evidence of aseptic loosening. Compared with previous studies, the incidence of high bone adaptions decreased substantially when a metaphyseal porous coating was added to the stem. Radiographic changes are associated with a higher filling ratio and cortical contact of the stem. Surgeons should avoid oversizing this type of uncemented humeral component.

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References

1. Atoun E, Van Tongel A, Hous N, Narvani A, Relwani J, Abraham R, et al. Reverse shoulder arthroplasty with a short metaphyseal humeral stem. Int Orthop 2014;38:1213-8. http://dx.doi.org/10.1007/s00264-014-2328-8
2. Bacle G, Nové-Josserand L, Garaud P, Walch G. Long-term outcomes of reverse total shoulder arthroplasty: a follow-up of a previous study. J Bone Joint Surg Am 2017;99:454-61. http://dx.doi.org/10.2106/JBJS.16.00223
3. Boileau P, Sinnerton RJ, Chuinard C, Walch G. Arthroplasty of the shoulder. J Bone Joint Surg Br 2006;88:562-75. http://dx.doi.org/10.1302/0301-620X.88B5.16466
4. Casagrande DJ, Parks DL, Torngren T, Schrumpf MA, Harmsen SM, Norris TR, et al. Radiographic evaluation of short-stem press-fit total shoulder arthroplasty: short-term follow-up. J Shoulder Elbow Surg 2016;25:1163-9. http://dx.doi.org/10.1016/j.jse.2015.11.067
5. Denard PJ, Noyes MP, Walker JB, Shishani Y, Gobezie R, Romeo AA, et al. Radiographic changes differ between two different short press-fit humeral stem designs in total shoulder arthroplasty. J Shoulder Elbow Surg 2018;27:217-23. http://dx.doi.org/10.1016/j.jse.2017.08.010
6. Gilot G, Alvarez-Pinzon AM, Wright TW, Flurin PH, Krill M, Routman HD, et al. The incidence of radiographic aseptic loosening of the humeral component in reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:1555-9. http://dx.doi.org/10.1016/j.jse.2015.02.007
7. Giuseffi SA, Streubel P, Sperling J, Sanchez-Sotelo J. Short-stem uncemented primary reverse shoulder arthroplasty: clinical and radiological outcomes. Bone Joint J 2014;96-B:526-9. http://dx.doi.org/10.1302/0301-620X.96B3.32702
8. Harmsen SM, Norris TR. Radiographic changes and clinical outcomes associated with an adjustable diaphyseal press-fit humeral stem in primary reverse shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:1589-97. http://dx.doi.org/10.1016/j.jse.2017.02.006
9. Khan A, Bunker TD, Kitson JB. Clinical and radiological follow-up of the Aequalis third-generation cemented total shoulder replacement: a minimum ten-year study. J Bone Joint Surg Br 2009;91:1594-600. http://dx.doi.org/10.1302/0301-620X.91B12.22139
10. Kilian CM, Press CM, Smith KM, O'Connor DP, Morris BJ, Elkousy HA, et al. Radiographic and clinical comparison of pegged and keeled glenoid components using modern cementing techniques: midterm results of a prospective randomized study. J Shoulder Elbow Surg 2017;26:2078-85. http://dx.doi.org/10.1016/j.jse.2017.07.016

11. King JJ, Farmer KW, Struk AM, Wright TW. Uncemented versus cemented humeral stem fixation in reverse shoulder arthroplasty. Int Orthop 2015;39:291-8. http://dx.doi.org/10.1007/s00264-014-2593-6
12. Levy JC, Anderson C, Samson A. Classification of postoperative acromial fractures following reverse shoulder arthroplasty. J Bone Joint Surg Am 2013;95:e104. http://dx.doi.org/10.2106/JBJS.K.01516
13. Levy O, Narvani A, Hous N, Abraham R, Relwani J, Pradhan R, et al. Reverse shoulder arthroplasty with a cementless short metaphyseal humeral implant without a stem: clinical and radiologic outcomes in prospective 2- to 7-year follow-up study. J Shoulder Elbow Surg 2016;25:1362-70. http://dx.doi.org/10.1016/j.jse.2015.12.017
14. Mather J, MacDermid JC, Faber KJ, Athwal GS. Proximal humerus cortical bone thickness correlates with bone mineral density and can clinically rule out osteoporosis. J Shoulder Elbow Surg 2013;22:732-8. http://dx.doi.org/10.1016/j.jse.2012.08.018
15. Matsen FA 3rd, Iannotti JP, Rockwood CA Jr. Humeral fixation by press-fitting of a tapered metaphyseal stem: a prospective radiographic study. J Bone Joint Sug Am 2003;85-A:304-8.
16. Melis B, DeFranco M, Lädermann A, Molé D, Favard L, Nérot C, et al. An evaluation of the radiological changes around the Grammont reverse geometry shoulder arthroplasty after eight to 12 years. J Bone Joint Surg Br 2011;93:1240-6. http://dx.doi.org/10.1302/0301-620X.93B9.25926
17. Morwood MP, Johnston PS, Garrigues GE. Proximal ingrowth coating decreases risk of loosening following uncemented shoulder arthroplasty using mini-stem humeral components and lesser tuberosity osteotomy. J Shoulder Elbow Surg 2017;26:1246-52. http://dx.doi.org/10.1016/j.jse.2016.11.041
18. Nagels J, Stokdijk M, Rozing PM. Stress shielding and bone resorption in shoulder arthroplasty. J Shoulder Elbow Surg 2003;12:35-9. http://dx.doi.org/10.1067/mse.2003.22
19. Nolan BM, Ankerson E, Wiater JM. Reverse total shoulder arthroplasty improves function in cuff tear arthropathy. Clin Orthop Relat Res 2011;469:2476-82. http://dx.doi.org/10.1007/s11999-010-1683-z
20. Phadnis J, Huang T, Watts A, Krishnan J, Bain GI. Cemented or cementless humeral fixation in reverse total shoulder arthroplasty? A systematic review. Bone Joint J 2016;98-B:65-74. http://dx.doi.org/10.1302/0301-620X.98B1.36336
21. Raiss P, Edwards TB, Deutsch A, Shah A, Bruckner T, Loew M, et al. Radiographic changes around humeral components in shoulder arthroplasty. J Bone Joint Surg Am 2014;96:e54. http://dx.doi.org/10.2106/JBJS.M.00378
22. Raiss P, Schmitt M, Bruckner T, Kasten P, Pape G, Loew M, et al. Results of cemented total shoulder replacement with a minimum follow-up of ten years. J Bone Joint Sug Am 2012;94:e1711-0. http://dx.doi.org/10.2106/JBJS.K.00580
23. Romeo AA, Thorsness RJ, Sumner SA, Gobezie R, Lederman ES, Denard PJ. Short-term clinical outcome of an anatomic short-stem humeral component in total shoulder arthroplasty. J Shoulder Elbow Surg 2018;27:70-4. http://dx.doi.org/10.1016/j.jse.2017.05.026
24. Sanchez-Sotelo J, Wright TW, O'Driscoll SW, Cofield RH, Rowland CM. Radiographic assessment of uncemented humeral components in total shoulder arthroplasty. J Arthroplasty 2001;16:180-7.
25. Schnetzke M, Coda S, Raiss P, Walch G, Loew M. Radiologic bone adaptations on a cementless short-stem shoulder prosthesis. J Shoulder Elbow Surg 2016;25:650-7. http://dx.doi.org/10.1016/j.jse.2015.08.044
26. Schnetzke M, Preis A, Coda S, Raiss P, Loew M. Anatomical and reverse shoulder replacement with a convertible, uncemented short-stem shoulder prosthesis: first clinical and radiological results. Arch Orthop Trauma Surg 2017;137:679-84. http://dx.doi.org/10.1007/s00402-017-2673-3
27. Throckmorton TW, Zarkadas PC, Sperling JW, Cofield RH. Radiographic stability of ingrowth humeral stems in total shoulder arthroplasty. Clin Orthop Relat Res 2010;468:2122-8. http://dx.doi.org/10.1007/s11999-010-1299-3
28. Verborgt O, El Abiad R, Gazielly DF. Long-term results of uncemented humeral components in shoulder arthroplasty. J Shoulder Elbow Surg 2007;16:S13-8. https://doi.org/10.1016/j.jse.2006.02.003
29. Wiater JM, Moravek JE Jr, Budge MD, Koueiter DM, Marcantonio D, Wiater BP. Clinical and radiographic results of cementless reverse total shoulder arthroplasty: a comparative study with 2 to 5 years of follow-up. J Shoulder Elbow Surg 2014;23:1208-14. http://dx.doi.org/10.1016/j.jse.2013.11.032