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Cementless curved short stem shoulder prostheses with a proximal porous coating: ingrowth properties at 2-5 years of radiological follow-up with clinical correlation

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Background: Little is known about the way the newest generation of stems integrate into the proximal humerus and their effect on the surrounding bone. Factors that may influence ingrowth have not been investigated.

Methods: A consecutive cohort study was conducted that examined 74 anatomical, reverse, or pyrocarbon hemiprostheses, using a curved modular short stem with a proximal porous coating 2-5 years postoperatively (mean 35 months). X-rays were reviewed by 2 examiners independently. Bone loss was scored with 1 point per zone with partial and 2 points per zone with complete resorption (10 zones). The Constant score was used for clinical correlation. Multiple linear regression was employed to investigate correlations between variables.

Results: No subsidence or shift of the stems occurred. Two of 74 patients showed 1 zone of periprosthetic lucency of 1 mm. The filling ratio averaged 0.54 (range: 0.36-0.75). Thirty patients (40.5%) displayed bone resorption, first seen at 16.6 months (range: 3-40 months), commonly in zones 1 and 5. A total of 22 patients had ≥1 zone with partial resorption, and 8 (10.8%) developed full thickness resorption after 32 (range: 10-49) months.One new finding was that female sex and older age accounted for 51% of the variation of the filling ratio. A high filling ratio, especially when >0.55, correlated with bone resorption ($P < .001$). Age, sex, and prosthesis type did not directly predict bone resorption. Bony sclerosis correlated with a high filling ratio ($P = .019$) and thereby indirectly with resorption. A direct correlation between sclerosis and resorption was narrowly insignificant ($P = .058$) once correcting for the filling ratio. Reverse shoulder prosthesis had a higher filling ratio than total shoulder prosthesis patients ($P < .001$), resulting indirectly in more bone resorption. The preoperative diagnosis did not significantly correlate with the filling ratio ($P = .59$) or the resorption score ($P = .69$). A varus or valgus alignment did not predict resorption ($P = .21$) or the formation of sclerotic lines ($P = .93$). Bone loss did not correlate with clinical results.

Conclusions: These short stems are firmly anchored 2-5 years postoperatively. However, significant bone loss, linked to a high filling ratio (>0.55), is observed proximally around these stems. The development of sclerotic lines around the stem indicates oversizing. Other factors were not found to have a significant effect on stem ingrowth. The implantation of stems with a large filling ratio is more common in older females and in patients receiving reverse shoulder prosthesis. Autologous impaction bone grafting could downsize the required stem. If adequate hold is not afforded by a suitably small stem, cementation is advisable.

Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Shoulder prosthesis; short stem; resorption; remodeling; radiological; pyrocarbon

Ethical approval was sought and granted by the ethics commission of the medical faculty of the Ludwig-Maximilians-University Munich (reference no. 667-15) in advance of study commencement.

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Uncemented short stems with a proximal porous coating are becoming widely used in anatomical, reverse, and hemi-shoulder arthroplasties.[9,11] Previous short stem prostheses, without the proximal porous coating, have been found to have high rates of aseptic loosening.[3] The clinical results that can be achieved using this latest implant type have been shown to be at least comparable to standard shafts.[16,20] However, the way this newest generation of stems integrate into the bone and their effect on the surrounding bone stock is yet to be examined in detail.

Stress shielding is a reduction of bone density resulting from decreased mechanical stimulation of bone surrounding an implant (Wolf's law). It is a problem that was first described in hip prostheses, but has since been found after shoulder arthroplasty.[7,17] Shortening the humeral component of a shoulder prosthesis brings about a more natural stress distribution,[6] so could ameliorate stress shielding caused by the implant. This is important as bone resorption could affect the long-term clinical function of the prostheses, increase the likelihood of periprosthetic fracture, and make revision surgery more difficult.

The filling ratio of the prosthesis in the proximal humerus has been shown to be an important predictor of bone resorption in previous studies.[16-18,20] The filling ratio gives an indication of the size of the prosthesis relative to the patient's bone structure. Larger prostheses are stiffer than thinner ones. The stiffness dictates how much force is conducted to the distal end of the implant. Stiff shafts conduct a greater proportion of load forces to the distal tip of the prosthesis, shielding the metaphysis. Conversely, thin shafts are more flexible and convey more load to the proximal bone, avoiding stress shielding.

Recently other authors have begun to describe the radiological properties of this newest range of short stem prostheses, with a proximal porous coating.[16,18,20,22] Of these, Schnetzke and Raiss both found, mirroring the findings of the first generation of short stem prostheses, that a high filling ratio was linked to increased bone remodeling. However, their analysis did not consider the interaction of different variables such as age, sex, diagnosis, and all prosthesis types (reverse shoulder prosthesis [RSA], total shoulder prosthesis [TSA], or hemiprostheses) on the remodeling processes observed. Nor did they differentiate between anabolic and catabolic developments (sclerosis vs. resorption); the relationship and significance of these are still to be uncovered. Tan et al[22] showed a trend to similar levels of stress shielding, but with more medial calcar resorption in the absence of the proximal porous coating when compared with prostheses with the coating. However, this was a comparison study with small numbers, and the findings were not statistically significant. A clear recommendation of how to avoid bone loss due to remodeling when implanting these second generation short stem shoulder prostheses has not been made.

The aim of this study was therefore to describe the radiological ingrowth properties of short stem shoulder prostheses with a proximal porous coating. Furthermore, we set out to explain the remodeling processes observed, investigate their interactions with other factors, and correlate these with the clinical outcome.

Materials and methods

Patient population and study design

We conducted a consecutive cohort study of 74 of 103 patients who were operated with a second-generation modular short stem shoulder prosthesis with a proximal porous coating between May 2013 and June 2015 at Agatharied Hospital. Implanted were anatomical (TSA), reverse (RSA), or hemiprostheses with a pyrocarbon head (PyC) (Aequalis Ascend Flex; Wright Medical, Bloomington, IL, USA). All 103 patients were invited for follow-up examinations. Our department had clinical follow-up data for 76 and x-ray images with adequate quality and projection for 74 of these 103 patients 2-5 years postoperatively (mean: 35, range: 23-60 months). Nine patients had complications leading to revision or rendering them incomparable to the rest of the cohort; the others were lost to follow-up. Reasons for this were old age, inability to travel, refusal of follow-up, and death unrelated to the prosthesis. This paper reports on the radiological findings of this cohort using the x-ray images taken at follow-up examinations, investigates interacting factors, and correlates these with the clinical outcome.

Prostheses and operative technique

Titanium short stem uncemented modular prostheses with a proximal porous coating (Aequalis Ascend Flex, Wright Medical) were implanted in 3 forms: hemiarthroplasty using a PyC, anatomic TSA, and RSA. The cementless stem achieves metaphyseal fixation through bony ingrowth after a press-fit implantation. The oval-shaped stem takes the path of least resistance during implantation, which helps to guide this into the natural retrotorsion of the humeral head. The glenoid retroversion was calculated relative to the Friedman line,[10] the inclination according to the Maurer angle[15] using the preoperative x-rays and computed tomography.

The operative technique uses the deltopectoral approach. In all cases, the subscapularis was taken down in the ‘‘peel-off‘‘ technique. The humeral head is resected in a manner depending on the type of prosthesis (see below). The proximal humerus was sequentially prepared using a sounder to define the width of the medullary canal and a compactor to check for the definitive implant size. All stems in this series were uncemented. The subscapularis tendon was repaired in all cases transosseously in the double-row technique.

RSA

For reversed prostheses, a cut was made at 132.5° of inclination, using a guide, aiming for a final inclination of 145° when including 12.5° of the inlay. The height of the resection should place the highest point of the tray at the level of the tip of the greater tuberosity. The glenoid baseplate was implanted with the inferior border flush to the inferior glenoid with 0-10° of inclination and a retroversion of <10°. If the retroversion was >10°, this was corrected with the use of autologous wedge-shaped cancellous bone grafting (wedged BIO-RSA) under the base plate (4 cases). In addition, in 2 cases with extreme glenoid wear, BIO-RSA was employed to lateralize the long peg base plate. All other RSA patients received the standard base plate with 25 mm or 29 mm diameter, depending on the native glenoid size. The size of the metaglene was 36 for females and 42 for males, and this was implanted with an inferior overlap of at least 5 mm. The humeral trial with the tray in position 6 and the required inlay was then reduced into the joint. The surgeon checked for deltoid tension, stability, range of motion, and impingement. Finally, the definitive humeral stem with the reversed head components, assembled on a back table, was implanted.

TSA

For the anatomical prostheses, a free-hand resection along the anatomical neck, after removal of osteophytes, was undertaken. The natural inclination was then matched using a prosthesis with 127.5°, 132.5°, or 137.5° of inclination. Minimal reaming of the glenoid, according to the radius of the curvature of the glenoid, was undertaken, and a cemented keeled glenoid was implanted. The humeral trial with the required head was then reduced into the joint and examined as described for RSA above. Finally, the definitive humeral stem with the anatomical head component, assembled on a back table, was implanted.

PyC

The technique for the preparation and implantation of the humeral component mirrored what was described for TSA. The joint capsule was mobilized and the labrum preserved. In some cases with Walch B1 and B2 glenoids, these were treated with minimal reaming (so as to spare as much glenoid bone as possible) and then perforation of any remaining areas of sclerosis with a 1.2-mm Kirschner wire. The size and rotation of the head were then chosen to maximize the coverage of the resected surface whilst avoiding overlap. After trialing, the final stem was implanted and the Pyrocarbon head was mounted in vivo in the optimum rotation with the spring impactor.

Radiological assessment

Two experienced examiners (CG and BDK) independently scrutinized the patients' x-rays in 3 planes on a diagnostic monitor in the manor described by Denard et al.[7] Where intraobserver differences occurred, the cases were discussed and a consensus reached. The location of adaptations found was described in terms of the 10 zones, as depicted in Fig. 1. The filling ratio was calculated by taking an average of the bone vs. prosthesis diameter measured at 4 sites: proximally and distally in both the anteroposterior (AP) and axillary views, as shown in Fig. 2. To better differentiate and quantify bone resorption, a new scoring system was employed: it was categorized into partial (osteopenia) and complete (full thickness) resorption and scored with 1 point for every zone with partial and 2 points for every zone with complete resorption.

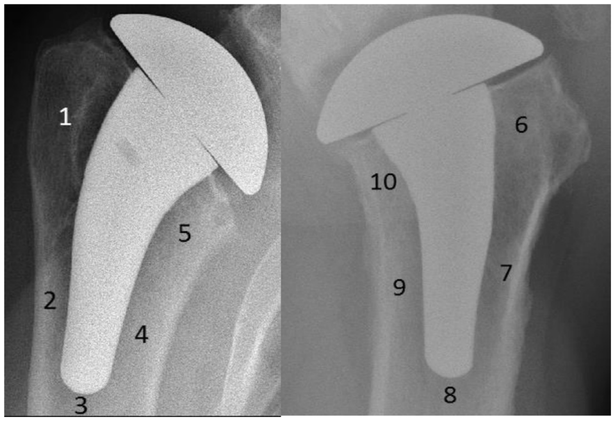

Figure 1 The 10 zones around the proximal humerus in the anteroposterior (AP) and axillary views.

Clinical evaluation

Patients were examined in our follow-up clinic at regular intervals by experienced examiners. The Constant score[4] was calculated pre- and postoperatively and used as a quantitative marker for the clinical outcome. Delta values (postoperative – preoperative) were used to allow for a more reliable comparison between subjects.

Statistics

Statistical models using multiple linear regression and hierarchical multiple linear regression were constructed to investigate correlations between the variables. This was performed using the SPSS V25.0 (IBM, Armonk, NY, USA) software.

Results

The demographics of the cohort of 74 patients who were analyzed for this study are shown in Table I.

Implantation properties

A total of 55 stems were centered, 14 in the valgus and 5 in the varus alignment (illustrated in Fig. 3). The filling ratio, as described above, averaged at 0.54 (range: 0.36-0.75). No subsidence or shift of the prosthesis was observed in any patients.

Bony adaptations

The bony adaptations that were found are summarized in Table II. An example of reactive bony sclerosis (also called condensation lines) is shown in Fig. 4. Ten of these patients had sclerosis in zone 3, 4 cases in zone 2, and 3 patients in zone 4. Four patients also had sclerotic reactions in the proximal zones: 3 patients in zone 1 and 1 patient in zone 6.

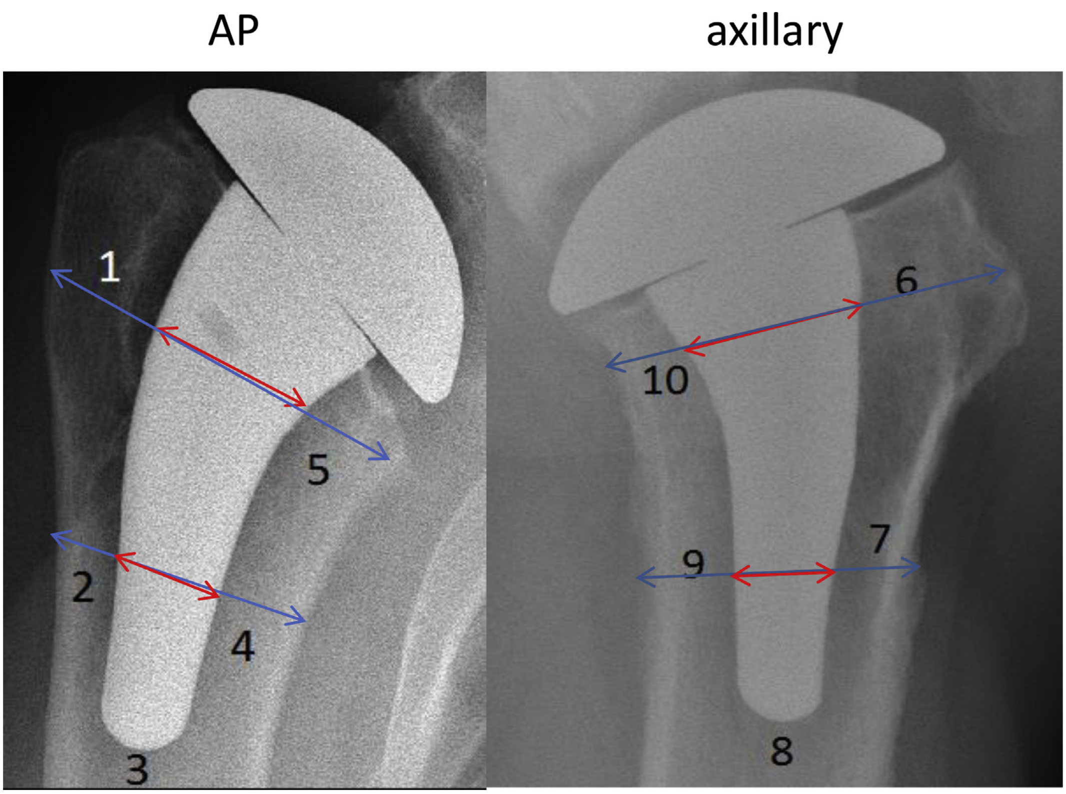

Figure 2 Method of determining the filling ratio in 2 x-ray planes.

Table I Patient population demographics

	Number	Age (yr)	Sex	Diagnoses	Follow-up (mo)
TSA	21	71.1 (range: 62-84)	14 Female	21 primary osteoarthritis	34 (range: 23-52)
RSA	32	74.1 (65-84)	26 Female	7 primary osteoarthritis 24 cuff tear arthropathy 1 irreparable rotator cuff tear	39 (range: 23-60)
PyC	21	58.3 (22-84)	4 Female	14 primary osteoarthritis 1 fracture sequelae 3 avascular necrosis 3 arthritis resulting from instability	29 (range: 23-48)

TSA, total shoulder prosthesis; *RSA*, reverse shoulder prosthesis; *PyC*, pyrocarbon head.

These were accompanied by scleroses in the central distal zone in 3 cases and in zone 2 (lateral distal) in 1 case. All cases with sclerosis in the proximal zones had prostheses that were centered in alignment. Of those with sclerosis in zone 3, all but one was centered in alignment. Reactive sclerosis in zone 2 was present in cases with the centered or varus alignment, never with valgus. Two patients who developed bony scleroses had a valgus alignment; in both cases, scleroses were observed only in zone 4.

Cortical thinning was observed in 30 patients (40.5%). Of these, 22 patients had at least 1 zone with partial resorption and 8 (10.8%) additionally had 1 or more zones with full thickness resorption. Partial resorption in zones 1 and 5 was the most common, with 15 and 17 cases, respectively. Two patients had partial resorptions in zone 10, 1 patient in zone 7 and 1 patient in zone 2. These were first seen radiologically at an average of 16.6 months (range: 3-40 months). The average resorption score, as described above, was 0.84 (range: 0-6). Full thickness resorption was present in 2 patients in zone 1, 3 patients in zone 2 (proximal part), 2 patients in zone 5, and 1 patient in zone 6. An example of this is shown in Fig. 5. The transition from partial to complete resorption was first seen on average after 32 (range: 10-49) months. It can be observed

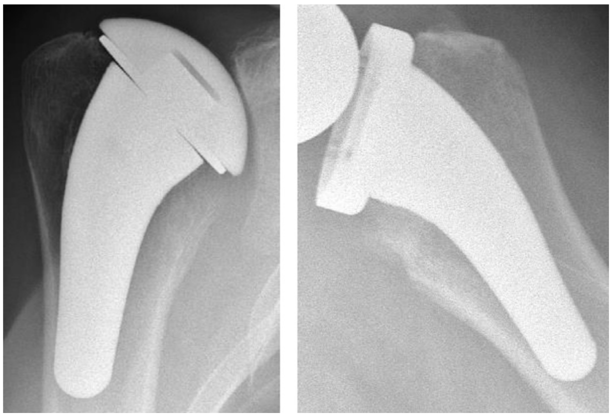

Figure 3 Examples of the varus and valgus alignment of the implanted short stem prostheses.

Table II Types of bony adaptations observed and number of cases in which these occurred

Bony adaptation	Number of cases
Periprosthetic lucency	2 (each 1 mm in zone 1)
Reactive bony sclerosis	14
Partial thickness resorption	30
Full thickness resorption	8

that progressive osteopenia takes place with loss of bone density and cortical thickness. Following this, the bone collapses all the way down to the prosthesis, as shown in Fig. 6.

Statistical correlations

The outcomes of the linear regression analysis are displayed in Table III. There was a strong correlation between a high filling ratio and more bone resorption ($P < .001$), especially when the filling ratio exceeded 0.55 (see Fig. 7). Age and sex predict 51% of the variation in filling ratio ($P < .001$). A higher bone resorption score did not significantly correlate with the Constant score gained ($P = .17$). The diagnosis leading to surgery did not significantly correlate with the filling ratio ($P = .59$) or the resorption score ($P = .69$). The prosthesis type had no significant relationship with the resorption score ($P = .47$). The presence of a varus or valgus alignment vs. a centered one did not correlate with the development of condensation lines ($P = .93$). A varus or valgus alignment was also not predictive of increased bone resorption ($P = .42$). A higher filling ratio correlated significantly with the development of reactive bony sclerosis ($P = .019$), explaining 8.1% of the variation in sclerosis.

In a hierarchical multiple linear regression model, when accounting for the effect of the filling ratio first, age ($P = .22$) and sex ($P = .95$) do not have any significant direct association with bone resorption. The presence of a reactive bony sclerosis seemed to be a significant predictor of bone resorption ($P = .003$) when tested independently; however, when correcting for its collinearity with the filling ratio, sclerosis added little variation to the model (3%) and was an insignificant factor ($P = .058$). A comparison of the remodeling processes between RSA and TSA showed more resorption in the RSA group, as well as a higher filling ratio in RSA patients. Once correcting for the effect of the filling ratio, there was no significant difference in resorption score between RSA and TSA ($P = .70$). A specific comparison of resorption in zone 1 in RSA vs. TSA patients, which could be different due to the absence of the rotator cuff in many RSA patients, did not show a significant difference ($P = .081$).

Discussion

Larger prostheses carry more forces from the shoulder joint to the proximal diaphysis, shielding the metaphysis and thereby causing bone remodeling. This effect may also be fortified by the loss of intraosseous blood supply.[14] Our finding that patients with a filling ratio below 0.55 had few problems with bony remodeling largely fits with the study by Raiss et al,[18] who described an average filling ratio of 0.57 in patients with low levels of bony adaptations. In contrast to the method proposed by Denard,[7] Raiss measured the filling ratio using the endosteal bone diameter (a smaller distance, making the ratio compared with the stem larger) and only in the AP projection (where the shaft is thicker). This is the reason why the average diameter of low remodeling patients was on the upper end of our safe cutoff for patients with little resorption. Also, in addition to describing what filling ratio patients with low remodeling have, we have assessed how large the filling ratio is allowed to be without risking a lot of bone resorption using this stem. The shape of the stem has been found to influence stress shielding and bone remodeling;[1,21,24] therefore, the critical filling ratio may vary when using other short stem prostheses. The pattern of bone resorption is that the proximal medial and lateral zones (1 and 5) are most commonly affected. The proximal area of zone 2 is then involved in the collapse of bone down to the stem, often creating an hour glass-like formation.

In our cohort, 17 of 74 patients (23%) displayed medial calcar osteopenia, which is considerably less than the 83% reported by Schnetzke et al[19] in 2016 for the previous model of this prosthesis. This may be a result of the proximal porous coating, which allows more transfer of load to the metaphyseal bone than the previous stem did.

Another adaptation that has previously been described is that of sclerosis of the cancellous bone surrounding the shaft, often around the distal tip, also called "condensation lines."[18,20] A new finding is the appearance of these scleroses at the proximal end of the stem, possibly due to the proximal porous coating, which gives this prosthesis hold

Table III Effect of independent variables on dependent variables

Correlation	Variability influenced (%)	P value
Filling ratio with bone resorption score	39	<.001
Age and sex with the filling ratio	51	<.001
Age and sex with bone resorption score	18	.00067
Bone resorption score with Constant score	2.6	.17
Diagnosis with the filling ratio	0.39	.59
Diagnosis bone resorption score	0.22	.69
Filling ratio with reactive sclerosis	8.1	.019
Varus/valgus alignment with reactive sclerosis	0.0016	.93
Varus/valgus alignment with bone resorption score	0.89	.42
Prosthesis type with bone resorption	0.71	.47
Reactive sclerosis with bone resorption score	11	.003
RSA vs. TSA on resorption score	9.8	.021
RSA vs. TSA on the filling ratio	36	<.001
RSA vs. TSA on resorption score in zone 1	5.7	.081
When correcting for the effect of the filling ratio first		
Age and sex with bone resorption score	1.3	.22 and .95, respectively
Reactive sclerosis with bone resorption score	3.0	.058
RSA vs. TSA on resorption score	0.19	.70

RSA, reverse shoulder prosthesis; *TSA*, total shoulder prosthesis.
The extent to which the independent variable influences the variability in the dependent variable is shown as %, the significance in terms of a *P*-value.
Age and sex were tested in combination as they are colinear in our cohort (men were younger).

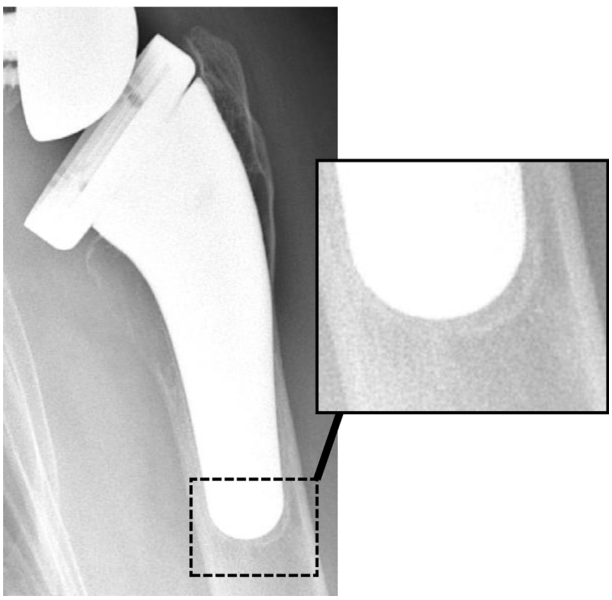

Figure 4 Example of bony sclerosis around the tip of a large prosthesis 2 years postoperatively in a 67-year-old female patient.

in the proximal metaphysis. The formation of sclerosis, we have been able to show, does not seem to be directly linked to bone resorption. Instead, it mainly correlates indirectly, as it also occurs in patients with a higher filling ratio more commonly. A slight correlation may be present however, given the marginal *P*-value of .058, responsible for 3% of variation in resorption.

The alignment of the prosthesis in the proximal humerus (varus, valgus, or centered) does not influence the formation of sclerosis. It does however dictate where sclerosis may occur, as it impacts on the areas where loads and forces are transferred to and carried by the bone. When bony sclerosis occurs in centered prostheses, it is found centrally at the tip of the stem with occasional additional scleroses in the proximal zones—axial load bearing. Patients with sclerotic reactions in zone 2 (lateral to the tip of the stem) have either a centered or varus alignment, never valgus. Finally, a valgus alignment seems to direct a sclerotic reaction medially of the tip of the stem.

Most of the adaptations observed appear in the AP radiograph and therefore occur medial or lateral to the shaft. This may be due to the shape of the shaft, which is thickest and least flexible at this point and could also be influenced by the direction of the forces that are applied during the movement of the shoulder. Despite the proximal porous coating, it seems that when prostheses are large and anchor at the distal tip, forces are not passed on to the proximal metaphysis, resulting in stress shielding and bone resorption here. If the shape of the prosthesis was revised to be thinner at the tip and have a more flexible stem, more force may be shared with the proximal bone.

Female sex and older age were described by a previous study to influence bony remodeling;[18] however, in our analysis, we were able to explain that this relationship is only an indirect one. Age and sex influence the relative size of prostheses implanted, most likely due to poorer bone

Figure 5 Example of full thickness bone loss in zone one 1 and the proximal part of zone 2, as well as partial resorption in zone 5 in a 70-year-old female patient.

quality, and it is only through this that older patients and those of female sex had more bone resorption.

In our cohort, there was no direct relationship between the type of prosthesis implanted and bone remodeling. As TSA and RSA have polyethylene components and PyC does not, it seems that the remodeling processes seen cannot be explained by polyethylene wear, as has been suggested in other settings.[1,2] Periprosthetic osteolysis is commonly caused by an inflammatory reaction to polyethylene wear particles. Only 2 patients (2.7%) were found to have 1 zone each of lucency of 1 mm in our cohort. This is at a stark contrast with the results achieved using previous models of short stem shoulder prostheses, which have shown rates of lucent lines of 71%.[3] The low rate of lucent zones in this most recent stem type, when compared with previous models, may be in part a result of the proximal porous coating that integrates into the bone or fills with fibrous tissue[24] and may act as a barrier to polyethylene debris matter, as this migrates best along surfaces without a porous coating.[1,24] Nevertheless, RSA patients did show more resorption than TSA, mediated through a higher filling ratio in this subgroup. Interestingly, the preoperative diagnosis did not show a relationship with the filling ratio. This is probably because TSA patients all had primary osteoarthritis (OA) and there were also a lot of primary OA patients in the RSA group. However, the OA patients who were treated with RSA are more likely to have high-grade disease with posterior subluxation and therefore a rotator cuff insufficiency. It may be that these and the cuff tear arthropathy (CTA) patients, who are the other big diagnosis group to receive RSA, have a comparatively low cancellous bone density resulting in a larger filling ratio. The increased sheer forces the stems of RSA patients are subjected to do not seem to affect the remodeling process significantly, perhaps just replacing the effect of forces from the rotator cuff.

Revision operations in patients with a lot of bone resorption will be challenging. Therefore, as ease of revision is one of the main arguments for the implantation of uncemented prostheses, it must be considered that these are not a good option for patients where the implantation of a small prosthesis does not afford good hold. Preoperatively, this can more likely be expected when operating older female patients, or when planning RSA, according to our findings. A maximum size of prosthesis that can be implanted whilst avoiding overfilling should be calculated. Intraoperatively, it may be necessary to adapt the surgical technique to the bone quality and its resulting hold after impaction, as ascertained using the twist test. If the largest calculated prosthesis that can be implanted without exceeding a filling ratio of 0.55 does not find satisfactory hold in the proximal humerus, there are 2 alternative options. The transfer of autologous cancellous bone graft from the resected humeral head to the humeral metaphysis to increase bone stock has been found to be successful at ensuring fixation.[12,13,23] This may enable the implantation of an adequately small prosthesis with sufficient stability. If this is not possible, the implantation of a cementless prosthesis should be abandoned. Cemented prostheses cause a more even distribution of forces to the surrounding bone and allow for the implantation of thinner, less stiff prostheses, as a result of which they cause significantly less stress shielding.[1,5,8,17,21] Cementation may therefore be the alternative option to revert to if adequate fixation cannot be achieved with a small stem.

Limitations

The inherently retrospective design of this type of study makes direct comparisons between male/female, old/young, and different prostheses as well as diagnoses difficult. As is commonly the case in studies of shoulder surgery, a larger cohort size would have increased the reliability of our findings further. A total of 29 of the cohort of 103 patients were not able to be analyzed for this study, largely due to lack of follow-up data. This reduces the reliability of our findings, as we cannot be sure that the 74 patients analyzed fully represent the entire cohort. As the range of development of resorption was 3-40 for partial and 10-49 for full thickness resorption, it is likely that some patients at the lower end of the range of follow-up would have developed further bone resorption in time. The

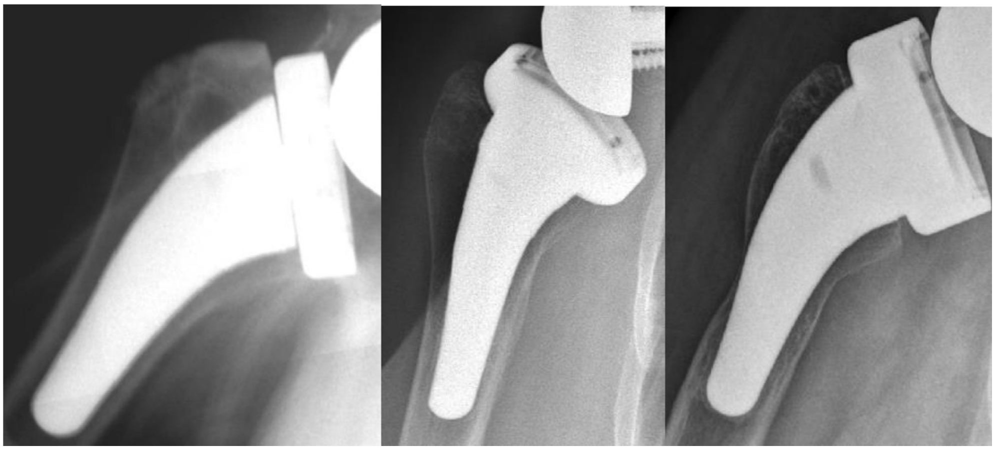

Figure 6 Transition from good bone stock postoperatively, to osteopenia after 24 Months months and eventually collapse of the bone down to the prosthesis after 37 months in a 69-year-old female patient.

absence of a clinical correlation with bone remodeling is a finding that mirrors what has been described by other authors.[18,20] However, as there are only short- to mid-term data available on this thus far, it may be that a correlation is found in long-term studies in the future.

A problem with retrospectively analyzed x-ray images is the ubiquitous slight differences in projection. Although only patients with x-rays of adequate quality and projection, where all 10 zones could be reliably analyzed, were included, slight rotational differences could have led to decreased accuracy of the results. Having said this, our scoring system for bone resorption is relatively coarse, so does not require perfect images to lead to reproducible results. Also, these are the kinds of images that clinicians encounter regularly, making our method transferable to everyday clinical practice. Nonetheless, it may be that a method that accurately measures bone density and volume could uncover relationships between resorption and other factors more sensitively. As the area between zones 1 and 2 is a common site for bone loss, the previously described and used zones are not ideal in describing the adaptations around these prostheses.

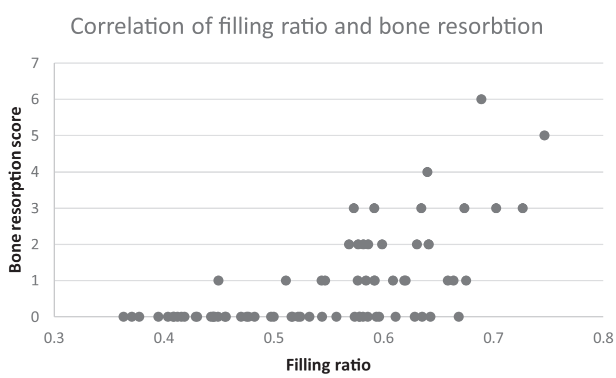

Figure 7 Scatter plot depicting the strong correlation between the filling ratio and bone resorption.

Conclusions

Cementless short stem shoulder prostheses with a proximal porous coating are firmly embedded 2-5 years postoperatively, seemingly with improvements in comparison to previous models of this stem.

Overall, large shafts with a filling ratio of over 0.55 appear to anchor distally, often causing a sclerotic hyperdensity of cancellous bone here. Formation of sclerosis can be seen as a marker of overfilling in the follow up clinic. A high filling ratio is also likely to lead to bone resorption at the proximal metaphysis, as this is shielded from physical stresses. The filling ratio is influenced by the age and sex of the patient and is also higher in RSA patients. Older and female patients, as well as those receiving RSA, are thereby indirectly at increased risk of periprosthetic bone remodelling.

When sufficient stability cannot be attained with a small stem, autologous bone grafting from the resected humeral head to decrease the prosthesis size needed should be considered. Alternatively, it is advisable to revert to the use of cemented prostheses when adequate fixation cannot be achieved with a press-fit implant of a safe size.

Disclaimer

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References

1. Bauer TW, Schils J. The pathology of total joint arthroplasty: II. Mechanisms of implant failure. Skeletal Radiol 1999;28:483-97.
2. Boileau P. Complications and revision of reverse total shoulder arthroplasty. Orthop Traumatol Surg Res 2016;102:S33-43. https://doi.org/10.1016/j.otsr.2015.06.031
3. 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. https://doi.org/10.1016/j.jse.2015.11.067
4. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res 1987:160-4.
5. Corten K, Bourne RB, Charron KD, Au K, Rorabeck CH. Comparison of total hip arthroplasty performed with and without cement: a randomized trial. A concise follow-up, at twenty years, of previous reports. J Bone Joint Surg Am 2011;93:1335-8. https://doi.org/10.2106/jbjs.J.00448
6. Denard PJ, Noyes MP, Walker JB, Shishani Y, Gobezie R, Romeo AA, et al. Proximal stress shielding is decreased with a short stem compared with a traditional-length stem in total shoulder arthroplasty. J Shoulder Elbow Surg 2018;27:53-8. https://doi.org/10.1016/j.jse.2017.06.042
7. Denard PJ, Raiss P, Gobezie R, Edwards TB, Lederman E. Stress shielding of the humerus in press-fit anatomic shoulder arthroplasty: review and recommendations for evaluation. J Shoulder Elbow Surg 2018;27:1139-47. https://doi.org/10.1016/j.jse.2017.12.020
8. Digas G, Karrholm J, Thanner J. Different loss of BMD using uncemented press-fit and whole polyethylene cups fixed with cement: repeated DXA studies in 96 hips randomized to 3 types of fixation. Acta Orthop 2006;77:218-26. https://doi.org/10.1080/17453670610045948
9. Dillon MT, Ake CF, Burke MF, Singh A, Yian EH, Paxton EW, et al. The Kaiser Permanente shoulder arthroplasty registry: results from 6,336 primary shoulder arthroplasties. Acta Orthop 2015;86:286-92. https://doi.org/10.3109/17453674.2015.1024565
10. Friedman RJ, Hawthorne KB, Genez BM. The use of computerized tomography in the measurement of glenoid version. J Bone Joint Surg Am 1992;74:1032-7.
11. Kim SH, Wise BL, Zhang Y, Szabo RM. Increasing incidence of shoulder arthroplasty in the United States. J Bone Joint Surg Am 2011; 93:2249-54. https://doi.org/10.2106/jbjs.J.01994
12. Levy O. Reverse shoulder arthroplasty: biomechanics, clinical techniques, and current technologies. New York: Springer; 2016.
13. Lucas RM, Hsu JE, Gee AO, Neradilek MB, Matsen FA III. Impaction autografting: bone-preserving, secure fixation of a standard humeral component. J Shoulder Elbow Surg 2016;25:1787-94. https://doi.org/10.1016/j.jse.2016.03.008
14. Marenzana M, Arnett TR. The key role of the blood supply to bone. Bone Res 2013;1:203-15. https://doi.org/10.4248/br201303001
15. Maurer A, Fucentese SF, Pfirrmann CW, Wirth SH, Djahangiri A, Jost B, et al. Assessment of glenoid inclination on routine clinical radiographs and computed tomography examinations of the shoulder. J Shoulder Elbow Surg 2012;21:1096-103. https://doi.org/10.1016/j.jse.2011.07.010
16. 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. https://doi.org/10.1016/j.jse.2016.11.041
17. Nagels J, Stokdijk M, Rozing PM. Stress shielding and bone resorption in shoulder arthroplasty. J Shoulder Elbow Surg 2003;12:35-9. https://doi.org/10.1067/mse.2003.22
18. Raiss P, Schnetzke M, Wittmann T, Kilian CM, Edwards TB, Denard PJ, et al. Postoperative radiographic findings of an uncemented convertible short stem for anatomic and reverse shoulder arthroplasty. J Shoulder Elbow Surg 2019;28:715-23. https://doi.org/10.1016/j.jse.2018.08.037
19. 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. https://doi.org/10.1016/j.jse.2015.08.044
20. Schnetzke M, Rick S, Raiss P, Walch G, Loew M. Mid-term results of anatomical total shoulder arthroplasty for primary osteoarthritis using a short-stemmed cementless humeral component. Bone Joint J 2018; 100-B:603-9. https://doi.org/10.1302/0301-620x.100b5.Bjj-2017-1102.R2
21. Sumner DR, Galante JO. Determinants of stress shielding: design versus materials versus interface. Clin Orthop Relat Res 1992:202-12.
22. Tan MT, Read JW, Bokor DJ. Does proximal porous coating in short-stem humeral arthroplasty reduce stress shielding? Shoulder Elbow 2019;11:56-66. https://doi.org/10.1177/1758573218773533
23. Wirth MA, Lim MS, Southworth C, Loredo R, Kaar TK, Rockwood CA Jr. Compaction bone-grafting in prosthetic shoulder arthroplasty. J Bone Joint Surg Am 2007;89:49-57. https://doi.org/10.2106/jbjs.E.01069
24. Yao Z, Lin T-H, Pajarinen J, Sato T, Goodman S. Chapter 12: Host response to orthopedic implants (metals and plastics). In: Badylak SF, editor. Host response to biomaterials. Oxford: Academic Press; 2015. p. 315-73.