Patterns of proximal humeral bone resorption after total shoulder arthroplasty with an uncemented rectangular stem

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Background: The aim of this study was to assess the timing and location of cortical bone resorption after total shoulder arthroplasty with an uncemented rectangular stem and investigate its effect on shoulder function up to 5 years after implantation.

Methods: Between June 2003 and September 2006, 183 consecutive total shoulder arthroplasties were performed, 133 of which received a cementless rectangular stem as indicated by primary or post-traumatic osteoarthritis (OA). The 5-year postoperative follow-up rate was 80%. Standardized radiographic controls and clinical assessments were performed at 6 weeks, 6 months, and 1, 2, and 5 years.

Results: Twenty-two patients (17%) showed full-thickness cortical bone resorption, 21 of whom were diagnosed with Sperling zone 2 resorption. The maximum craniocaudal distance of full resorption averaged 19.1 mm (range, 5.6-46.7 mm). The median distance progressed significantly from 9.6 mm to 13.8 mm between 6 and 12 months (P = .005). The risk of bone resorption was 3.1 times higher for post-traumatic OA patients than for those with primary OA. The occurrence of bone resorption increased significantly with increasing stem diameters relative to the humeral diameter. There was no significant effect of bone resorption on functional outcome.

Conclusion: Full-thickness cortical bone resorption in the proximal posterolateral humerus after receipt of a cementless rectangular stem has a prevalence of 17%, mostly occurring within the first year after surgery. Risk factors include age, post-traumatic conditions, and larger stem sizes relative to the humerus. This is a radiographic phenomenon without significant impairment of function or need for revision within 5 years after surgery.


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Keywords: Proximal humerus; cortical bone resorption; total shoulder arthroplasty; rectangular stem prosthesis; uncemented; shoulder function

Institutional review board/ethics committee approval was granted by the following institution: Cantonal Ethics Committee of Zürich, Zürich, Switzerland. Approval for the study (19/2001, Quality Management and Outcome Measurement of the Upper Extremity (QUOMUEX)) was granted on December 18, 2001.

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1058-2746/$ - see front matter © 2014 Journal of Shoulder and Elbow Surgery Board of Trustees.
http://dx.doi.org/10.1016/j.jse.2014.02.024
Fixation of humeral components in total shoulder arthroplasty can be achieved with cemented or uncemented stems. To accomplish the fixation of uncemented stems in humeral bone, different designs have been used, varying from circumferential porous coating for tissue ingrowth to cylindrical stems for diaphyseal fixation or stems with a tapered metaphyseal component for press-fit fixation in the humeral metaphysis. After stem implantation, remodeling of the cortical bone can result in full-thickness resorption in the humerus. Nagels et al. assessed 70 humeral hemiarthroplasties in a mixed patient population with rheumatoid arthritis and osteoarthritis (OA) after a mean follow-up period of 5.3 years; a reduction of cortical bone thickness was observed in 6 cases (9%) whereas 3 were reported to have full-thickness resorption. This phenomenon of bone resorption was also more frequently associated with larger stem sizes relative to the humeral diameter as well as in osteoporotic bone of rheumatoid arthritis patients.

Adaptive bone remodeling that can lead to varying degrees of bone loss has also been studied and quantified in the femur. When the femur is fixed with an intramedullary stem, the bone shares its load-carrying capacity with the implant and, as a consequence, reduces stress, which in turn causes bone to reduce its mass. These studies have led to the understanding that bone remodeling is a ubiquitous phenomenon that may occur with cemented and uncemented implants. However, an increased prevalence of adverse effects such as loss of function, femoral fractures, or loss of fixation has not been documented. To our knowledge, the extent to which resorption of full cortical bone in the humerus appears and how it develops over time are unknown. The purpose of this study was to radiographically assess the timing and location of humeral cortical bone resorption related to shoulder arthroplasty using a cementless rectangular stem. Possible risk factors for bone resorption, as well as the potential consequences for shoulder function, were also investigated.

**Materials and methods**

**Patient selection**

Between June 2003 and September 2006, 183 consecutive total anatomic shoulder arthroplasties were performed and documented at our institution in 147 patients. Of these arthroplasties, 149 used a cementless stem after primary or secondary OA. A total of 34 arthroplasties were excluded because of treatment received for revision arthroplasty (n = 4), acute fractures (n = 8), and rheumatoid arthritis (n = 16), as well as arthroplasty after OA with a cemented stem (n = 4) or hemiarthroplasty (n = 2). The 133 eligible patients comprised 84 women with a mean age of 70 years (range, 53-88 years) and 49 men with a mean age of 64 years (range, 23-80 years) at the time of the index surgery. Of 133 patients, 96 had degenerative (primary) OA and 37 had post-traumatic (secondary) OA. Bilateral total shoulder replacement was performed in 16 of the 133 patients, and only the first surgery was considered in these cases.

Five years after surgery, 106 patients (80% follow-up rate) were available for clinical and radiographic assessment. Ten patients died of causes unrelated to the index surgery, and 17 were lost to follow-up. One patient had no available follow-up radiographic records and was excluded from the evaluation of osteolysis. One patient was lost to follow-up and radiographic assessment after the 6-week examination.

**Prosthesis implantation**

A deltoidectomy approach was used to implant a Promos prosthesis (Smith & Nephew Orthopaedics, Rotkreuz, Switzerland) in all patients. The humeral component of this prosthesis consists of a titanium alloy stem with a grit-blasted surface. A rectangular body is inserted at the top of the stem, which allows the height of the humeral head to be modified while serving as the base for the inclination part. Inclination of the humeral head may thus be adapted to the anatomic requirements. The humeral head is added to the inclination part in an eccentric position, so as to reconstruct the former anatomic orientation. The humeral stem has a rectangular cross section and tapers lengthwise to a thin tip. It is inserted by manual hammering until press-fit is achieved in the zone of the meta-diaphyseal junction. The prosthesis is assembled in situ after fixation of the humeral stem.

**Follow-up examinations**

All patients underwent regular examinations by use of standardized assessment tools, which included radiographic and clinical evaluation preoperatively as well as at 6 months and 1, 2, and 5 years after surgery. The functional outcome instruments used for clinical assessment were the Constant-Murley score; Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire; Shoulder Pain and Disability Index; and clinical American Shoulder and Elbow Surgeons Standardized Shoulder Assessment (CASES) and patient American Shoulder and Elbow Surgeons Standardized Shoulder Assessment questionnaires. Radiographs were also taken at 6 weeks and 3 years postoperatively.

**Radiographic assessment**

Radiographic examinations were performed in 3 standard planes. Two anteroposterior (AP) views were taken with the patient in an upright position: the scapula of the affected side was flat against the x-ray plate, and the contralateral side was held at an angle of 30° with the forearm in flexion and supination. The x-ray beam was tilted 20° cranio-caudal and centered on the joint so that the joint line was visible as a symmetrical line. The first AP-view radiograph was taken with the arm in internal rotation and the second in external rotation. The third radiograph was taken in the axillary view with the patient sitting and the arm held in abduction with the x-ray film lying under the axilla. The central beam was oriented perpendicularly to the middle of the axilla and parallel to the thorax. All digital radiographs were evaluated with a picture archiving communications system.

One trained, independent observer (H.D.) retrospectively examined all radiographs for signs and measurements of full-thickness bone resorption using digital measuring tools (VISUS Technology Transfer, Bochum, Germany) (Fig. 1). The location of full cortical bone resorption was assessed by measuring the distance from the base of the stem component to the starting point of...
bone resorption (Fig. 2) and categorized according to the zones defined by Sperling et al.\textsuperscript{23} The craniocaudal length of areas showing full-thickness cortical bone resorption was recorded to determine the extent of resorption.

The humerus and stem widths (D-humerus and D-stem, respectively) were measured 6 weeks postoperatively on the AP view in internal rotation, at the level of close contact between the stem and humeral cortex identified at the superior quarter of the stem length measured from its metaphysis base to its tip. At that level, both D-humerus and D-stem were measured on a line perpendicular to the stem longitudinal axis, and the ratio of D-humerus to D-stem was calculated. The larger the ratio, the thicker the humeral cortices are relative to the stem size at the level of fitting. For 30 shoulders, the measurements could not be used for various reasons, including the lack of a visible prosthesis stem end (n = 20), missing 6-week internal rotation AP radiographs (n = 7), the presence of a bone shaft fissure (n = 1), and anomalous measurements because of postoperative trauma (n = 2).

### Statistical analysis

The occurrence, location, and extent of bone resorption were described by time point using standard descriptive statistics. In particular, the time point at which bone resorption was primarily observed was tabulated. Progression (ie, craniocaudal length of observed bone resorption areas) over time in affected patients and humeri (nominated as the bone resorption group) was explored by use of the Wilcoxon signed rank test to compare each follow-up data point separately with the 6- and 12-month values. The bone resorption group was compared with the non–bone resorption group (ie, patients and humeri with no full-thickness bone resorption observed on any radiograph throughout the 5-year follow-up period) with regard to baseline factors including patient age and gender, diagnosis (primary/secondary OA), and occurrence of previous operations (yes/no), as well as the ratio of D-humerus to D-stem, using logistic and binomial regression. The continuous factors of age and width ratio were categorized to explore potential threshold effects. All factors were first analyzed separately and then combined into a multivariable logistic regression model. Significant factors were finally included into a binomial regression model to derive adjusted relative risks of association and their 95% confidence intervals.

The influence of bone resorption on the Constant-Murley, DASH, Shoulder Pain and Disability Index, CASES, and patient satisfaction was explored by use of the Wilcoxon signed rank test to compare each follow-up data point separately with the 6- and 12-month values. The bone resorption group was compared with the non–bone resorption group (ie, patients and humeri with no full-thickness bone resorption observed on any radiograph throughout the 5-year follow-up period) with regard to baseline factors including patient age and gender, diagnosis (primary/secondary OA), and occurrence of previous operations (yes/no), as well as the ratio of D-humerus to D-stem, using logistic and binomial regression. The continuous factors of age and width ratio were categorized to explore potential threshold effects. All factors were first analyzed separately and then combined into a multivariable logistic regression model. Significant factors were finally included into a binomial regression model to derive adjusted relative risks of association and their 95% confidence intervals.
Table I Occurrence and extent of bone resorption during 5-year postoperative period

<table>
<thead>
<tr>
<th>Follow-up</th>
<th>NA</th>
<th>No. of patients with no SFBR up to follow-up time point</th>
<th>No. of patients with SFBR at follow-up time point but with SFBR at previous follow-up examination</th>
<th>Mean (SD) (mm)</th>
<th>Mean (SD) (mm)</th>
<th>P value vs 6 mo</th>
<th>P value vs 12 mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 mo</td>
<td>1</td>
<td>6</td>
<td>—</td>
<td>10.8 (8.5)</td>
<td>9.6 (3.0-36.0)</td>
<td>.005</td>
<td></td>
</tr>
<tr>
<td>12 mo</td>
<td>3</td>
<td>1</td>
<td>15</td>
<td>16.4 (9.0)</td>
<td>13.8 (4.4-34.0)</td>
<td>.011</td>
<td>.170</td>
</tr>
<tr>
<td>2 y</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>18.3 (10.2)</td>
<td>15.7 (5.6-38.0)</td>
<td>.008</td>
<td>.055</td>
</tr>
<tr>
<td>3 y</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>20.6 (10.9)</td>
<td>20.3 (8.8-46.7)</td>
<td>.208</td>
<td>.401</td>
</tr>
<tr>
<td>5 y</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td>16.6 (10.1)</td>
<td>14.3 (5.2-35.8)</td>
<td>.204</td>
<td>.401</td>
</tr>
</tbody>
</table>

NA, not available; SFBR, signs of full bone resorption.

The mean and median values indicate the mean and median craniocaudal distance, respectively, and quantify the extent of bone resorption.

* P value from Wilcoxon signed rank test after comparing craniocaudal distance (ie, extent of bone resorption) at respective time point with that reported at 6 months.

1 P value from Wilcoxon signed rank test after comparing craniocaudal distance (ie, extent of bone resorption) at respective time point with that reported at 12 months.

Results

Occurrence, location, and extent of bone resorption

During the 5-year postoperative period, a total of 22 patients (17% of 132 patients) were observed with signs of cortical bone resorption. Sperling zone 2 bone resorption was detected on internal rotation AP-view radiographs for 21 patients, and 1 patient was reported to have Sperling zone 6 resorption based on external rotation radiographs. For all patients except 3, the resorption zones were detected within 12 months after surgery (Table I). For the remaining 3 patients, bone resorption was observed at the 24-month follow-up time point. At the 5-year postoperative examination, no further patients were found with signs of full-thickness cortical bone resorption.

The average maximum craniocaudal distance quantifying the extent of resorption in the 22 affected patients was 19.1 mm (range, 5.6-46.7 mm). The median extent of bone resorption progressed significantly from 9.6 mm to 13.8 mm between 6 and 12 months (P = .005) (Table I). The median values documented at the 2-, 3-, and 5-year follow-up examinations were 15.7 mm, 20.3 mm, and 14.3 mm, respectively, and did not differ significantly from the 12-month value (P > .055) (Table I and Fig. 3).

Comparison between patients with and without bone resorption

The mean age of patients with and without bone resorption was 71 years (range, 48-88 years) and 67 years (range, 23-85 years), respectively (Table II); patients with bone resorption were aged, on average, 4.4 years older than patients without bone resorption (P = .046). Patients aged older than 60 years were 4.2 times more likely to show signs of bone resorption compared with younger patients (P = .032) (Table II). Patients treated for secondary OA had a 3.1 times higher risk of having bone resorption compared with patients with primary OA (P = .001) (Table II). The occurrence of bone resorption was significantly related to the humerus–stem diameter ratio: the risk of bone resorption was 2.3 and 2.8 times higher for patients with a ratio of more than 1.3 to 1.4 (P = .052), and less or equal to 1.3.
respectively, compared with those with a ratio higher than 1.4 (Table II). Gender and whether the patient had previously undergone shoulder surgery were not significant influencing factors on the risk of bone resorption.

### Influence of bone resorption on functional outcomes

All postoperative functional scores were strongly related to the respective baseline values \( (P < .001) \), and in particular, the Constant-Murley \( (P < .001) \), DASH \( (P = .045) \), and CASES \( (P = .001) \) scores significantly deteriorated between 12 months and 5 years after surgery (Table III). There were no significant effects of age and gender on bone resorption after adjusting for the baseline score. After we considered these parameters, there was no significant difference in all functional outcomes for patients with bone resorption compared with those without bone resorption \( (P = .257 \text{ to } P = .790) \) (Fig. 4).

### Discussion

In this study, full-thickness cortical bone resorption in the superoposterior humerus after total anatomic shoulder replacement with an uncemented, tapered rectangular stem was observed in 22 patients (17%). This phenomenon was localized exclusively in zone 2 as defined by Sperling et al., except in 1 patient with a post-traumatic condition who was reported to have Sperling zone 6 bone resorption. Neither tilt/subsidence of the stem nor aseptic loosening was observed in all 22 patients. To our knowledge, no prior study conducted with cementless stems has described full cortical bone resorption in a defined zone except for that of Nagels et al.,

The term “full-thickness bone resorption” is a purely radiographic description of loss of cortical bone in at least 1 radiographic view. Nagels et al. described complete bone resorption of 1 cortex adjacent to the humeral stem after reviewing 70 hemiarthroplasties in a mixed population of patients with OA and rheumatoid arthritis over a mean postoperative period of 5.3 years. They described a reduction in cortical bone thickness in the superolateral metaphysis and the greater tuberosity in 6 of 70 patients (9%) with round stems. Furthermore, resorption of full-thickness cortical bone was reported in 3 of the 6 patients; this rate is lower than the rate of 17% of patients with full bone resorption in our series. Among the 6 patients reported by Nagels et al., reduction in bone thickness occurred in 5 who received uncemented stems and in a single patient with a...
Proximal humerus resorption patterns after TSA

Mixed model analysis of influence of bone resorption on functional outcome scores

<table>
<thead>
<tr>
<th>Model parameter</th>
<th>Functional outcome score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Constant-Murley DASH SPADI PASES CASES</td>
</tr>
<tr>
<td></td>
<td>Coef (95% CI)</td>
</tr>
<tr>
<td>Occurrence of bone resorption</td>
<td>0.57</td>
</tr>
<tr>
<td>Baseline preoperative score</td>
<td>0.95</td>
</tr>
<tr>
<td>Female patient</td>
<td>0.62</td>
</tr>
<tr>
<td>Age at time of surgery</td>
<td>0.01</td>
</tr>
<tr>
<td>2-y follow-up time point</td>
<td>2.18</td>
</tr>
<tr>
<td>5-y follow-up time point</td>
<td>5.26</td>
</tr>
</tbody>
</table>

The P value from the Wald test is presented for each parameter in the models.

Effect of nominated follow-up time point relative to 12-month follow-up time point.

In our study, full cortical bone resorption was detected between 6 and 12 months after the index surgery in 19 of 22 patients. Full bone resorption in the remaining 3 patients was observed at the 24-month follow-up, and no further case was observed after this time point. The extent of bone resorption progressed between 6 and 12 months but did not show any significant progression throughout the later postoperative examinations. Notably, for some patients, the initial measurements of cortical bone resorption were found to be shorter or not detected at the later follow-up examinations. Bone regeneration is most improbable in this context. We believe that this observation is most likely due to varying projection angles or tilting of the radiographic beam making the resorption zone invisible. Therefore, we acknowledge the imperfection of the measurement method using 2-dimensional radiography. Computed tomography scans, in particular 3-dimensional reconstructions, would be better suited to determine the precise extent of bone loss in further scientific studies (Fig. 1, B) and have been shown to be the most reliable method for quantifying bone remodeling to measure the extent of bone resorption after total shoulder arthroplasty. This was not implemented in our routine follow-up examination schedule; however, because of the high proportion of cases followed (80%), as well as the repeated measurements at each follow-up, we suggest that the radiographic method allows a practical approximation of the real dimension of bone resorption. Standard radiographs in at least 2 different planes seem to be sufficient, except in the circumstance when a dramatic change in shoulder function occurs.

Because the progression of cortical bone resorption occurs early in the postoperative period, the likelihood that the tapered stem is fitted very tightly in the meta-diaphyseal zone increases. The shape of the rectangular, tapered press-fit stem prevents linear and rotational translation and reduces the relative movement between metal and bone. In the area of stem fixation, the cross section of the humerus changes from an elliptical to a more cylindrical shape, a geometric transition that may explain why the posterior lateral rim of the prosthesis wedges very tightly on a relatively thin cortex. At the level of press-fixation, the 4 edges of the stem bear the stress and therefore reduce the load on the adjacent cortex.

Nagels et al assumed that the observed bone resorption is a result of stress shielding. From hip surgery, it is known that the load and stress reduce in a long bone cortex adjacent to a solid metallic implant, resulting in bone resorption. Furthermore, the load on the proximal femur is reduced when a rigid distal fixation of the stem is achieved by wedging of the tip of the cemented stem prosthesis. They did not specify whether the 3 cases with full-thickness cortical bone resorption were observed equally in those with cemented stems and those with uncemented stems.

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study population. A possible explanation could be that any lowering of stress on the humeral cortex leads to bone resorption through stress shielding on the posterior edge, with a linear fusiform shape. Morgan et al.\textsuperscript{16} and Rispoli et al.\textsuperscript{19} described in detail the V-shaped insertion of the deltoid muscle on the proximal humerus. In some cases with extended zones of bone resorption, the posterior-superior deltoid insertion could be more distal. It could be plausible that the deltoid muscle insertion protects bone from stress shielding and, therefore, prevents further progression of resorption. Otherwise, the intraoperative reaming process of the proximal humerus might also have an influence; further investigations would be required to exclude this issue.

In our study, patient age and gender were not significantly associated with the occurrence of bone resorption. Patients treated for post-traumatic conditions had a higher risk of cortical bone resorption developing than those with degenerative OA. Because the study population of Nagels et al.\textsuperscript{17} included mostly patients with rheumatoid arthritis, the authors suggested that osteoporosis in rheumatoid patients could be a risk factor for bone resorption. It seems plausible to us that both the thin cortex in rheumatoid patients and the perfusion disturbances after trauma may facilitate resorption of bone when it is in very tight contact with the prosthesis. Our study shows that the occurrence of bone resorption is significantly related to the ratio between the humeral shaft and prosthetic stem diameter. The risk was more than twice as high if the humerus–stem diameter ratio was smaller than 1.4 (ie, large stems compared with the humeral diameter). This supports the previous observation by Nagels et al, who stated that the risk of bone resorption is greater with increasing stem size relative to the humeral diameter. It should be noted that the measurement of the humeral width may give an inaccurate estimation of the real thickness of the humeral cortex in the stem fixation zone. Nagels et al measured the humeral diameter at the tip of the stem, which may provide different measurements compared with those taken at the metaphyseal junction. Because of the extreme variations in the individual shape of the humeral shaft cylinder, it does not seem feasible to determine the exact fixation point of the stem preoperatively. We therefore believe that the risk of bone resorption increases with higher stem sizes, but on the basis of preoperatively measured humeral diameters, it remains difficult to predict the occurrence of post-implantation resorption.

Patients with cortical bone resorption showed no specific symptoms or impairment of shoulder function compared with those without resorption. Although differences in functional scores between the 2 patient groups were not statistically significant, a tendency for deterioration in the shoulder function of patients with bone resorption by the 5-year postoperative follow-up cannot be fully excluded. Because a similar observation has not been previously reported, a longer period of observation for these patients is warranted. This trend toward decreasing function could lead to the possibility that future revision of the stem may be required; the resorption of bone and the fact that the prosthesis is fully coated may lead to massive bone loss associated with stem explantation, which can dramatically affect future revision. With the use of a modular shoulder system, the main indication for stem explantation with the risk of bone loss might be periprosthetic infection.

**Conclusion**

Full-thickness bone resorption after implantation with a cementless rectangular stem may occur in the posterolateral cortex of the proximal humerus, with a prevalence of 17%. The rectangular press-fit stem provides stable fixation without subsidence or tilt over a period of
5 years. The risk of bone resorption development was higher in patients with post-traumatic conditions than in those with primary OA, as well as when larger stem diameters relative to the humeral diameter were used. This phenomenon is associated with neither component loosening nor a significant impairment of function 5 years after surgery. This appears to be a radiographic phenomenon without further need for revision.

Disclaimer
Support for this research was provided by the Schulthess Clinic.

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

Acknowledgment
The authors thank M. Wilhelmi, PhD, for the preparation and copyediting of this manuscript.

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