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Medial calcar bone resorption after anatomic total shoulder arthroplasty: does it affect outcomes?

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Background: The incidence of medial calcar resorption has been shown to be common after uncemented total shoulder arthroplasty (TSA). With etiologies including stress shielding, debris-induced osteolysis, and infection, the clinical impact of medial calcar resorption has not been specifically examined. The purpose of this study was to determine whether resorption is associated with inferior outcomes or higher rates of radiographic loosening in TSA patients.

Methods: We conducted a retrospective review of TSA patients with minimum 2-year clinical follow-up. Patient-reported and functional outcome measures were recorded preoperatively and postoperatively. Postoperative radiographs were evaluated for glenoid and humeral component loosening. A new calcar resorption grading system was introduced to quantify the degree of resorption and assess the progression.

Results: A total of 171 patients met the inclusion criteria, with average clinical and radiographic follow-up periods of 50 and 46 months, respectively. Calcar resorption was identified in 110 patients (64.3%). No significant overall differences were observed between the patients with and without calcar resorption. Subgroup analysis showed that patients with grade 3 resorption had a higher incidence of glenoid radiolucencies (50%, $P = .001$) and patients with a progression from grade 1 to grade 3 had higher incidences of glenoid (50%, $P = .003$) and humeral (9%, $P = .039$) radiolucencies.

Conclusion: Medial calcar resorption following TSA with a standard-length press-fit humeral component is common. Overall, no differences in patient-reported outcome measures or radiographic loosening were found compared with patients without calcar resorption. However, grade 3 calcar resorption and more dramatic progression of resorption should raise the suspicion of prosthetic loosening.

All work was performed at Holy Cross Orthopedic Institute and Holy Cross Hospital.
This study was approved by the Western Institutional Review Board (study No. 1179001) prior to its conduction.

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Total shoulder arthroplasty (TSA) has been demonstrated to successfully reduce pain and improve function in the severely arthritic shoulder.[5,12,16,19,20,27] While humeral stem loosening has traditionally been a rare event, bony resorption around the proximal portion of the stem has been commonly observed, with a reported incidence as high as 86%.[12] Bone resorption has been seen with all variations of humeral stem length,[5,12,16,19,20,27] as well as with newer stemless designs.[29]

The clinical significance of humeral bone resorption, as it relates to component loosening and implant failure, is still being elucidated. Numerous pathologic processes may lead to bone resorption of the medial calcar, ranging from more benign conditions such as stress shielding and remodeling to more concerning processes such as debris-induced osteolysis from glenoid and third-body wear or an evolving infection. A prior study by Raiss et al[19] demonstrated a strong association between calcar osteolysis and glenoid loosening with polyethylene wear.

Recent studies have assessed the degree of humeral stem internal remodeling by identifying radiographic findings such as spot welds, condensation lines, cortical thinning, and focal osteopenia in each of the humeral zones.[4,5,16,25] Despite evidence that these radiographic findings correlate with stress shielding and osteolysis, there has been no reported difference in clinical outcomes with increased bony adaptive changes. However, prior studies have not specifically examined the impact of the presence and degree of medial calcar resorption as it relates to clinical outcomes and complications, nor has there been any attention directed to the progression of calcar resorption. The purpose of this study was to determine whether the degree of medial calcar resorption, along with its progression, is associated with inferior outcomes or higher rates of radiographic humeral or glenoid loosening in patients undergoing anatomic TSA with a standard-length press-fit humeral stem. The hypothesis was that higher grades of calcar resorption would be associated with worse clinical outcomes and correlate with component loosening.

Materials and methods

We conducted a retrospective review of an institutional shoulder surgery repository to identify all patients treated with primary anatomic TSA between April 2009 and October 2015. The inclusion criteria identified consented patients treated with the same primary third-generation TSA system (Turon; DJO, Austin, TX, USA) with complete preoperative data and minimum 2-year follow-up clinical and radiographic data. Patients undergoing revisions and those treated with other TSA implant systems were excluded.

Patient-reported outcome measures (PROMs) were measured both preoperatively and postoperatively as part of the standard institutional shoulder surgery repository. PROMs included the Simple Shoulder Test score, American Shoulder and Elbow Surgeons total score, Single Assessment Numeric Evaluation score, and visual analog scale score for pain. Range-of-motion measurements were routinely obtained by recording the patient's best effort with a manual goniometer. Internal rotation was measured based on the highest midline segment of the back that could be reached; the segment reached was converted to a numeral.[28]

The senior author performed all TSA procedures by a deltopectoral approach using the same surgical technique.[14] A press-fit technique was used for humeral stem insertion in all cases. Humeral stem size was based on the first sequential broach that obtained rotational stability, typically achieving metaphyseal fixation rather than diaphyseal fixation. Morsalized bone graft from the humeral head was placed into the prepared humeral canal shortly before impaction of the final stem. The glenoid was prepared using standard noncannulated reamers, creating a concentrically matched surface for the glenoid component, often partially correcting glenoid version. The glenoid component was cemented in all cases, with pressurization of cement into the prepared glenoid surface and placement of cement behind the component prior to impaction.

Postoperatively, all patients were managed with an identical rehabilitation protocol. For the initial 6 weeks, patients were placed in a shoulder immobilizer and self-administered therapy focused on pendulum exercises. The second 6 weeks focused on a self-directed active-assisted stretching program. Strengthening and lifting were delayed for the first 3 months.

Postoperative anteroposterior (AP) and axillary radiographs from the initial postoperative visit and most recent visit were reviewed to assess component loosening. Consensus between at least 2 trained reviewers was required for this assessment. In cases with a lack of consensus, the senior author's opinion was used. The Lazarus and Sperling classifications were used in the evaluation of glenoid loosening and humeral stem loosening, respectively.[13,26] Gross glenoid loosening (Lazarus grade 5) was defined as complete radiolucency around the entire component, often with a shift in position. A humeral component was determined to be at risk of loosening based on the observation of radiolucent lines 2 mm or greater in 3 or more zones or a shift in the position of the stem.[22]

The initial postoperative radiograph was used to calculate filling ratios at the metaphyseal and diaphyseal levels with ImageJ software[23] (National Institutes of Health, Bethesda, MA, USA) using the measurement defined by Raiss et al.[21] Calcar resorption was evaluated based on comparison of the initial and most recent postoperative AP radiographs with a new grading system introduced to

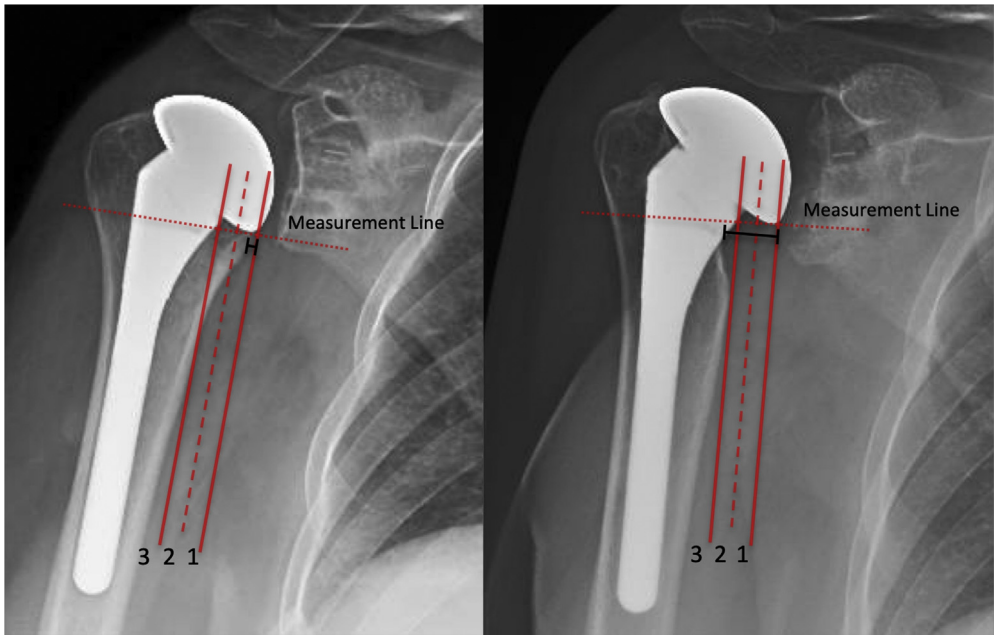

Figure 1 Calcar resorption grading system using anteroposterior radiographs. Calcar height is measured at the inferior level of the humeral head. As the calcar resorption progresses, the grade increases. Grade 1 denotes the zone between the solid medial line and the dashed line. Grade 2 denotes the zone between the dashed line and the solid lateral line. Grade 3 denotes the zone medial to the solid medial line. This patient shows significant progression from grade 1 at 3 months to grade 3 at final follow-up.

quantify the degree of medial calcar resorption (Fig. 1). Lines parallel to the humeral stem were drawn at the most medial aspect of the prosthetic head and at the head-neck junction, with a line drawn between these markers to estimate the percentage of calcar resorption at the inferior level of the prosthetic head. Grade 1 corresponded to less than 50% of the width of the medial head, grade 2 corresponded to 50% to 100% of the width of the medial head, and grade 3 corresponded to resorption that progressed past the head-neck junction with the humeral stem exposed. Progression was defined as a change in grade between the 3-month postoperative radiograph and the most recent postoperative radiograph obtained at a minimum of 2 years. When radiographs from both of these time points were not available, progression was not assessed.

In an effort to evaluate the reproducibility of the novel calcar resorption grading system, the initial postoperative, 3-month, and most recent postoperative AP radiographs were reviewed for each patient in random fashion independently by the senior author, a shoulder and elbow fellow, a resident, and a research fellow. The grade of calcar resorption was defined for the 3-month and most recent postoperative radiographs. Interobserver consistency was assessed.

Comparison analysis was performed between patients with identifiable calcar resorption and those without resorption. Subgroup analysis of patients with calcar resorption was then performed based on the grade of calcar resorption, in addition to comparison between those with progression of calcar resorption and those with stable calcar resorption. Analysis was performed based on age, body mass index (BMI), sex, PROMs, measured range of motion, and findings of postoperative radiographic component loosening.

Data were not normally distributed; thus, descriptive statistics including frequencies with percentages and medians with interquartile ranges were calculated for all variables. Patient outcomes by occurrence, classification, and progression of resorption were compared using the χ^2 test for categorical variables and the Mann-Whitney U test or Kruskal-Wallis test with Dunn multiple comparisons for continuous variables. To understand interobserver consistency in the identification of resorption, both the Cramér V (Φ_c) test and Φ coefficient test[3] were executed, as is appropriate for categorical-nominal data. The Cramér V test was used to evaluate interobserver correlation for all resorption grades, that is, grades 0 through 3; Φ correlation was used for binary interobserver data, wherein the identification of grade 3 resorption was indicated as 1 and all other grades were indicated as 0 (the rationale being that grade 3 is the primary variable of interest, as it is associated with component loosening). A post hoc power analysis was executed to ensure the appropriate avoidance of a type II error. Data analysis was performed using SPSS Statistics for Windows (version 25.0; IBM, Armonk, NY, USA). All statistical tests were 2-tailed, with an interpretation of significance associated with $P < .05$ and $\beta > 0.8$.

Results

The query identified 171 patients who met the inclusion criteria with an average clinical follow-up period of 50 months (range, 24-111 months) and average radiographic follow-up period of 46 months (range, 24-101 months). The medial calcar resorption cohort comprised 110 patients, representing an incidence of 64.3%. When present, calcar resorption was first observed at an average of 3 months (range, 1.4-7 months) after surgery.

No significant differences were observed between the patients with and without calcar resorption with respect to

Table I Patient characteristics by occurrence of calcar resorption (N = 171)

	Calcar resorption, median (IQR) or n (%)	No calcar resorption, median (IQR) or n (%)	*P* value
Patients	110 (64.3)	61 (35.7)	—
Age, yr	71.3 (65.9-75.4)	72.0 (65.3-75.6)	.874
Clinical follow-up, mo	48 (33.9-62.6)	49.7 (27.5-73.2)	.536
Radiographic follow-up, mo	41.3 (30.3-52.9)	41 (31.7-58.5)	.579
BMI, kg/m^2	28 (24.9-32.1)	29 (25.9-32.2)	.298
Male sex	50 (45.5)	36 (59.0)	.089
Glenoid loosening			
Any radiolucent lines	24 (21.8)	10 (16.4)	.395
Gross glenoid loosening	1 (1.6)	6 (5.5)	.424
Humeral radiolucent lines	2 (1.8)	0 (0)	.289
SST score			
Preop	3 (1-5)	3 (1-5)	.863
Postop	9 (7-12)	10 (8-11)	.430
Improvement	6 (3-8)	6 (4-8)	.595
SANE score			
Preop	33 (17-50)	33 (17-52)	.979
Postop	90 (75-96)	86 (69-97)	.471
Improvement	49 (23-73)	43 (15-70)	.412
ASES total score			
Preop	30 (18-42)	27 (18-42)	.992
Postop	90 (73-98)	88 (78-96)	.910
Improvement	55 (35-70)	53 (36-68)	.810
VAS pain score			
Preop	7 (5-8)	7 (6-9)	.282
Postop	0 (0-2)	0 (0-1)	.900
Improvement	−6 (−8 to −4)	−7 (−8 to −4)	.632
Active elevation, °			
Preop	90 (70-110)	105 (80-120)	.034
Postop	140 (129-151)	145 (135-155)	.050
Improvement	50 (25-70)	40 (20-65)	.396
Active external rotation, °			
Preop	20 (0-30)	20 (0-30)	.409
Postop	50 (35-60)	55 (45-60)	.327
Improvement	30 (20-45)	30 (20-50)	.848
Active internal rotation*			
Preop	2 (2-4)	2 (2-4)	.318
Postop	8 (6-8)	8 (4-8)	.303
Improvement	4 (2-6)	4 (2-6)	.462

IQR, interquartile range; *BMI*, body mass index; *SST*, Simple Shoulder Test; *Preop*, preoperatively; *Postop*, postoperatively; *SANE*, Single Assessment Numeric Evaluation; *ASES*, American Shoulder and Elbow Surgeons; *VAS*, visual analog scale.

* Active internal rotation was evaluated on a 10-point scale: 2 points, buttock or greater trochanter; 4 points, sacrum to L4; 6 points, L3 to L1; 8 points, T12 to T8; and 10 points, T7 to T1.

age, sex, or PROMs. Patients without medial calcar resorption had better preoperative forward elevation (P = .034) than patients with resorption. However, postoperative range-of-motion outcomes did not differ between groups (Table I). Overall, there were 7 cases of gross glenoid loosening but no cases of humeral stems at risk of loosening. Radiolucent lines around the distal portion of humeral components were seen in 2 patients with calcar resorption vs. 0 patients without calcar resorption (1.26% vs. 0.00%).

Subgroup analysis of patients with calcar resorption identified 14 patients (12.7%) with grade 1 calcar resorption, 74 (67.3%) with grade 2, and 22 (20%) with grade 3. Patients with grade 3 calcar resorption showed a higher incidence of glenoid radiolucent lines (50%, P = .001) than those with grade 1 (0%) or grade 2 (17.5%) calcar resorption. Patients with grade 3 calcar resorption also had a lower BMI than patients with grade 1 calcar resorption (Table II). No differences were observed among the 3 different calcar resorption grades

Table II Patient characteristics by calcar resorption grade (n = 110)

	Grade 1 calcar resorption, median (IQR) or n (%)	Grade 2 calcar resorption, median (IQR) or n (%)	Grade 3 calcar resorption, median (IQR) or n (%)	*P* value
Patients	14 (12.7)	74 (67.3)	22 (20.0)	—
Age, yr	70.6 (65.6-75.4)	72.3 (67.2-75.7)	69.1 (64.1-73.9)	.444
Clinical follow-up, mo	38.7 (27.5-58.8)	45.8 (30.4-62.6)	49.4 (38.1-70.7)	.249
Radiographic follow-up, mo	38.9 (32.3-49.2)	38.8 (27.6-53.3)	48.8 (36.9-67)	.231
BMI, kg/m^2	32.5 (21.2-36.4)*	27.9 (25.3-32.1)	26.1 (23.5-29.2)	.010
Male sex	6 (42.9)	37 (50.0)	7 (31.8)	.316
Glenoid loosening				
Any radiolucent lines	0 (0)*	13 (17.6)*	11 (50.0)	.001
Gross glenoid loosening	0 (0)	3 (4.1)	3 (13.6)	.146
Humeral radiolucent lines	0 (0)	0 (0)	2 (9.1)	.054
SST score				
Preop	3 (0-5)	3 (1-5)	3 (1-5)	.358
Postop	9 (7-11)	9 (7-12)	10 (6-11)	.921
Improvement	6 (4-8)	6 (3-8)	7 (2-9)	.647
SANE score				
Preop	31 (10-41)	37 (20-50)	37 (17-56)	.347
Postop	80 (68-92)	90 (79-96)	89 (63-99)	.506
Improvement	53 (21-78)	50 (24-73)	49 (11-77)	.914
ASES total score				
Preop	29 (21-42)	30 (18-43)	27 (15-40)	.649
Postop	84 (67-91)	90 (74-97)	88 (75-98)	.449
Improvement	59 (35-60)	55 (35-70)	58 (34-75)	.602
VAS pain score				
Preop	7 (6-8)	7 (5-8)	7 (7-8)	.599
Postop	0 (0-1)	0 (0-2)	0 (0-2)	.760
Improvement	−6 (−8 to −5)	−6 (−8 to −4)	−7 (−8 to −5)	.613
Active elevation, °				
Preop	93 (68-109)	90 (75-110)	80 (68-110)	.735
Postop	140 (113-160)	140 (128-150)	150 (128-153)	.542
Improvement	58 (16-71)	50 (25-65)	60 (23-85)	.432
Active external rotation, °				
Preop	20 (0-27)	20 (0-30)	10 (0-30)	.560
Postop	50 (45-60)	45 (35-60)	60 (40-60)	.123
Improvement	38 (20-45)	30 (13-45)	30 (30-53)	.219
Active internal rotation†				
Preop	2 (2-4)	2 (2-4)	4 (2-4)	.430
Postop	8 (8-10)	8 (6-8)	8 (7-10)	.161
Improvement	5 (4-6)	4 (2-6)	6 (1-6)	.405

IQR, interquartile range; *BMI*, body mass index; *SST*, Simple Shoulder Test; *Preop*, preoperatively; *Postop*, postoperatively; *SANE*, Single Assessment Numeric Evaluation; *ASES*, American Shoulder and Elbow Surgeons; *VAS*, visual analog scale.

* $P < .01$ with grade 3 calcar resorption as the reference category.

† Active internal rotation was evaluated on a 10-point scale: 2 points, buttock or greater trochanter; 4 points, sacrum to L4; 6 points, L3 to L1; 8 points, T12 to T8; and 10 points, T7 to T1.

regarding age, sex, PROMs, range of motion, or humeral loosening.

Progression of calcar resorption was also examined. Of the 110 patients who experienced calcar resorption, 53 (48.2%) were identified as having progression of calcar resorption. Patients with progression had a significantly lower BMI ($P = .030$) and less improvement in internal rotation ($P = .40$) than patients without radiographic progression of calcar resorption (Table III). Those with progression of calcar resorption had a similar clinical follow-up period but a longer radiographic follow-up period (38.1 months vs. 48.3 months, $P = .033$). However, no differences were observed between these 2 groups based on age, sex, improvement in PROMs, improvement in elevation or external rotation, or observation of glenoid or humeral loosening.

Analysis of the degree of progression highlighted further differences. There were 31 patients (28.2%) who

Table III Patient characteristics by occurrence of calcar resorption progression (n = 110)

	Progression of calcar resorption, median (IQR) or n (%)	No progression of calcar resorption, median (IQR) or n (%)	*P* value
Patients	53 (48.2)	57 (51.8)	—
Age, yr	71.6 (64.8-75.5)	70.7 (66.7-75.4)	.893
Clinical follow-up, mo	48.3 (36.4-62)	41 (29.8-64.5)	.511
Radiographic follow-up, mo	48.3 (35.8-60.9)	38.1 (28.3-49.5)	.033
BMI, kg/m^2	26.6 (24.7-30.4)	29.3 (25.9-32.8)	.030
Male sex	20 (37.7)	30 (52.6)	.117
Glenoid loosening			
Any radiolucent lines	15 (28.3)	9 (15.8)	.112
Gross glenoid loosening	3 (5.7)	3 (5.3)	.927
Humeral radiolucent lines	2 (3.8)	0 (0)	.230
SST score			
Preop	3 (1-5)	3 (1-5)	.602
Postop	10 (7-12)	9 (7-12)	.696
Improvement	6 (3-8)	6 (3-8)	.848
SANE score			
Preop	40 (20-56)	30 (15-50)	.141
Postop	90 (77-96)	90 (74-97)	.850
Improvement	48 (16-70)	55 (25-76)	.533
ASES total score			
Preop	28 (15-38)	32 (20-46)	.081
Postop	90 (73-98)	90 (72-98)	.625
Improvement	56 (37-75)	55 (33-68)	.311
VAS pain score			
Preop	7 (6-8)	7 (5-8)	.026
Postop	0 (0-2)	0 (0-1)	.256
Improvement	−7 (−8 to −5)	−5 (−8 to −3)	.200
Active elevation, °			
Preop	90 (73-110)	90 (70-110)	.846
Postop	140 (125-150)	140 (130-155)	.935
Improvement	50 (20-70)	50 (25-70)	.978
Active external rotation, °			
Preop	20 (0-30)	20 (0-30)	.929
Postop	50 (33-60)	50 (40-60)	.695
Improvement	30 (20-45)	30 (15-45)	.739
Active internal rotation*			
Preop	4 (2-4)	2 (2-4)	.113
Postop	8 (5-8)	8 (8-8)	.267
Improvement	4 (0-6)	6 (2-6)	.040

IQR, interquartile range; *BMI*, body mass index; *SST*, Simple Shoulder Test; *Preop*, preoperatively; *Postop*, postoperatively; *SANE*, Single Assessment Numeric Evaluation; *ASES*, American Shoulder and Elbow Surgeons; *VAS*, visual analog scale.

* Active internal rotation was evaluated on a 10-point scale: 2 points, buttock or greater trochanter; 4 points, sacrum to L4; 6 points, L3 to L1; 8 points, T12 to T8; and 10 points, T7 to T1.

progressed from grade 2 to grade 3 and 22 patients (20%) who progressed from grade 1 to grade 3 (Table IV). Patients who demonstrated more dramatic progression (from grade 1 to grade 3) had a significantly higher incidence of both glenoid and humeral radiolucent lines (Fig. 2) than patients who progressed from grade 2 to grade 3 and patients without progression. Patients with progression from grade 1 to grade 3 also had a lower BMI than those with no progression. Less improvement in internal rotation was observed in patients with progression from grade 2 to grade 3 compared with patients without progression.

Filling ratios assessed using the initial postoperative radiographs suggested a metaphyseal press-fit surgical technique, as the filling ratio at the metaphyseal region was 0.43 ± 0.1 (maximum, 0.66; minimum, 0.21) and the filling ratio at the diaphyseal region was 0.41 ± 0.08 (maximum, 0.59; minimum, 0.22).

Table IV Patient characteristics by progression of calcar resorption (n = 110)

	Calcar resorption progression from grade 2 to grade 3, median (IQR) or n (%)	Calcar resorption progression from grade 1 to grade 3, median (IQR) or n (%)	Calcar resorption without progression, median (IQR) or n (%)	*P* value
Patients	31 (28.2)	22 (20.0)	57 (51.8)	—
Age, yr	72.3 (66.3-76.3)	69.1 (64.1-73.9)	70.7 (66.7-75.4)	.402
BMI, kg/m^2	27.1 (24.7-31)	26.1 (23.5-29.2)*	29.3 (25.9-32.8)	.045
Clinical follow-up, mo	43.7 (25.8-58.9)	49.4 (38.1-70.7)	41 (29.8-64.5)	.264
Radiographic follow-up, mo	45.1 (28.7-60.9)	48.8 (36.9-67)	38.1 (28.3-49.5)	.081
Male sex	13 (41.9)	7 (31.8)	30 (52.6)	.224
Glenoid loosening				
Any radiolucent lines	4 (12.9)†	11 (50)‡	9 (15.8)	.003
Gross glenoid loosening	0 (0)	3 (13.6)	3 (5.3)	.103
Humeral radiolucent lines	0 (0)§	2 (9.1)*	0 (0)	.039
SST score				
Preop	4 (2-5)	3 (1-5)	2 (1-5)	.631
Postop	10 (8-12)	10 (6-11)	9 (7-12)	.869
Improvement	6 (3-8)	7 (2-9)	6 (3-8)	.827
SANE score				
Preop	40 (21-55)	37 (17-56)	30 (15-50)	.316
Postop	90 (84-95)	89 (63-99)	90 (74-97)	.854
Improvement	47 (21-70)	49 (11-77)	55 (25-76)	.823
ASES total score				
Preop	28 (14-37)	27 (15-40)	32 (20-46)	.219
Postop	90 (71-95)	88 (75-98)	90 (72-98)	.850
Improvement	55 (37-75)	58 (34-75)	55 (33-68)	.533
VAS pain score				
Preop	8 (6-8)	7 (7-8)	7 (5-8)	.083
Postop	0 (0-2)	0 (0-2)	0 (0-1)	.501
Improvement	−7 (−8 to −4)	−7 (−8 to −5)	−5 (−8 to −3)	.416
Active elevation, °				
Preop	95 (79-110)	80 (68-110)	90 (70-110)	.659
Postop	140 (125-150)	150 (128-153)	140 (127-155)	.423
Improvement	40 (20-65)	60 (23-85)	50 (26-69)	.374
Active external rotation, °				
Preop	25 (5-30)	10 (0-30)	20 (0-30)	.652
Postop	45 (30-60)	60 (40-60)	50 (37-60)	.153
Improvement	30 (10-43)	30 (30-53)	30 (15-45)	.313
Active internal rotation‖				
Preop	4 (2-4)	4 (2-4)	2 (2-4)	.255
Postop	8 (4-8)	8 (8-10)	8 (8-8)	.053
Improvement	2 (0-6)*	6 (1-6)	6 (2-6)	.030

IQR, interquartile range; *BMI*, body mass index; *SST*, Simple Shoulder Test; *Preop*, preoperatively; *Postop*, postoperatively; *SANE*, Single Assessment Numeric Evaluation; *ASES*, American Shoulder and Elbow Surgeons; *VAS*, visual analog scale.

* $P < .05$ with calcar resorption without progression as the reference category.

† $P < .01$ with grade 1 to grade 3 calcar resorption progression as the reference category.

‡ $P < .01$ with calcar resorption without progression as the reference category.

§ $P < .05$ with grade 1 to grade 3 calcar resorption progression as the reference category.

‖ Active internal rotation was evaluated on a 10-point scale: 2 points, buttock or greater trochanter; 4 points, sacrum to L4; 6 points, L3 to L1; 8 points, T12 to T8; and 10 points, T7 to T1.

This novel calcar resorption grading system was found to be reproducible among observers with various levels of experience. Interobserver correlations to measure the consistency of grading were shown to exhibit ''strong'' to ''very strong'' positive relationships,[3] as seen when each grade was evaluated independently (Φ_c correlation range, 0.425-0.616; Table V), as well as when grade 3 resorption was compared with resorption lower than grade 3 (Φ correlation range, 0.487-0.732; Table V). A significant and strong trend toward consistency in grading was found among all observers ($P < .001$, Table V).

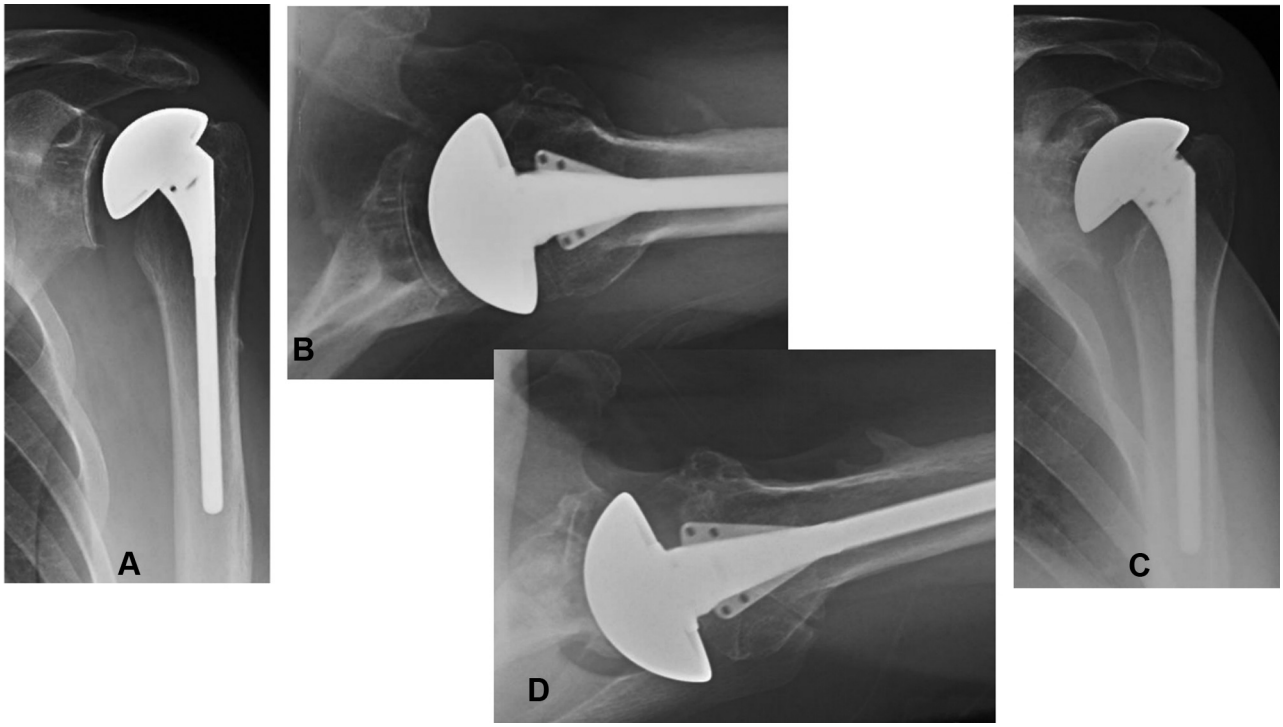

Figure 2 Anteroposterior (**A**) and axillary lateral (**B**) radiographs of a 70-year-old male patient 3 months after surgery. Comparison anteroposterior (**C**) and axillary lateral (**D**) radiographs at 88 months demonstrating a significant progression to grade 3 medial calcar resorption.

A post hoc, categorical power analysis demonstrated a 97.3% chance of avoidance of a type II error. This value is within the proposed $\beta > 0.8$ range; thus, the sample size was sufficient for this statistical evaluation.

Discussion

The results of this study demonstrate a reproducible grading system for calcar resorption. By use of this grading system, there was no overall clinical impact of medial calcar osteolysis following anatomic TSA at an average of 4 years' follow-up as functional outcomes and pain scores were no different among cohorts. However, with subgroup analysis, it became clear that patients who demonstrate a dramatic progression of calcar resorption (from grade 1 to grade 3) are more likely to have radiographic signs of glenoid and humeral loosening and that patients with grade 3 resorption have higher rates of glenoid loosening. These findings suggest that high-grade

Table V Interobserver correlation comparison for novel classification system among 4 observers with various experience grading resorption overall, as well as grading resorption as either grade 3 or not grade 3 (none, grade 1, or grade 2)

Primary observer	Secondary observer	Overall grading system		Comparison of grade 3 with other grades	
		Φ coefficient	*P* value	Φ coefficient	*P* value
Research fellow	Resident	0.523	<.001	0.602	<.001
	Shoulder and elbow fellow	0.425	<.001	0.529	<.001
	Senior author	0.459	<.001	0.487	<.001
Resident	Research fellow	0.523	<.001	0.602	<.001
	Shoulder and elbow fellow	0.578	<.001	0.619	<.001
	Senior author	0.616	<.001	0.732	<.001
Shoulder and elbow fellow	Resident	0.578	<.001	0.619	<.001
	Research fellow	0.425	<.001	0.529	<.001
	Senior author	0.502	<.001	0.712	<.001
Senior author	Resident	0.616	<.001	0.732	<.001
	Research fellow	0.459	<.001	0.487	<.001
	Shoulder and elbow fellow	0.502	<.001	0.712	<.001

calcar resorption may be a marker for prosthetic loosening.

Previous studies have reported varying rates of humeral bone resorption after shoulder arthroplasty, with the reported incidence ranging from 17% to 86%.[5,12,16,19,20,27] Inoue et al[12] reported the presence of humeral bone resorption in nearly 86% (n = 126) of 147 total patients undergoing TSA or humeral head replacement. The highest rates of humeral bone resorption were seen around the greater tuberosity, lateral diaphysis, and calcar regions (zones 1, 2, and 7, respectively).

Raiss et al[19] discussed radiographic changes around the humeral component in a large cohort of patients (N = 395) treated with standard-length shoulder arthroplasty with an average follow-up period of 8 years. While stress shielding was noted in 63% of uncemented humeral stems, calcar osteolysis was observed in 38.8% (n = 26) of the 67 patients undergoing press-fit standard-length TSA. Furthermore, proximal humeral osteolysis was more frequent in shoulders with glenoid loosening, and patients with a loosened glenoid component had a significantly lower Constant score. In addition, patients with partial or complete osteolysis at the proximal part of the humerus had a significantly lower Constant score (55 points vs. 67 points), less shoulder elevation, and less external rotation.

Despite several studies reporting on the observation of medial calcar osteolysis, no study has focused on the impact of the degree and progression of this specific radiographic observation on clinical outcomes. In our study, by use of a reproducible grading system, TSA patients with medial calcar resorption (n = 110, 64%) demonstrated no significant overall differences in postoperative outcomes or degree of radiographic loosening compared with TSA patients without medial calcar resorption (n = 61, 36%; Table I). However, when patients with calcar resorption were further characterized with a focus on the progression of resorption, it became clear that cases of more severe calcar resorption were associated with higher rates of component loosening (Table IV). This finding suggests that progression to more severe degrees of calcar resorption represents a concerning radiographic finding that should increase the suspicion of a pending prosthetic failure.

The clinical implications of calcar resorption are difficult to define, but advancing and/or severe loss of calcar bone may signal excessive third-body wear or undiagnosed infection causing macrophage-mediated osteolysis with a higher risk of implant failure. As recognized by Schnetzke et al,[25] risk factors for proximal bone loss and possible humeral loosening appear to include stress shielding, lack of proximal ingrowth coating, unrecognized chronic infection, third-body wear, and presence of underlying disease states other than primary osteoarthritis.

Stress shielding is primarily a measure of the internal remodeling following anatomic TSA and relates to changes in stress distribution in the proximal humerus created by humeral implants.[5] The prosthesis shares the load of the proximal humerus, and in accordance with Wolff's law, a change in the distribution of stress results in remodeling of the proximal humeral bone.[5,16,30] Schnetzke et al[24,25] and Nagels et al[16] observed that high filling ratios were associated with higher radiographic adaptations signifying bony resorption. In addition, short-stemmed implants with higher proximal cortical contact and collared designs have shown less stress shielding.[4,6] Raiss et al[19] showed that stress shielding was only observed in uncemented stems, but they did not find an association between stress shielding and inferior clinical outcomes or stem loosening. The clinical impact of stress shielding is likely minimal unless component loosening or rotator cuff failure results. To date, this has been an infrequent observation. It is possible that stress shielding represents a vast majority of the patients in this series with lower grades of calcar resorption, which were not found to influence clinical outcomes or the incidence of radiographic loosening. However, it is unlikely that diaphyseal fixation was responsible for this stress shielding, as the filling ratios in the metaphyseal and diaphyseal regions were 0.43 and 0.41, respectively.

Other risk factors for proximal humeral resorption appear to be more clinically significant.[1,8,9,15,18] Third-body wear related to polyethylene and/or cement debris contributes directly to debris-induced osteolysis, as has been shown extensively in the hip arthroplasty literature.[2,11] Raiss et al[19] observed high rates of osteolysis of the proximal humerus in the setting of polyethylene wear. This was more evident in TSA patients with metal-backed glenoid components, with the development of polyethylene wear and proximal humeral osteolysis in 67% of patients. These patients also had lower functional outcome scores and worse range of motion. The cement technique used in this series included placement of cement onto the backside of the glenoid component. While this has been shown to improve initial glenoid fixation,[17] the thin cement mantles that result could have led to cracks in the cement and resulting wear particles. With only 6 patients with gross glenoid loosening, our study may be underpowered to detect a significant impact of third-body wear on clinical outcomes in patients with calcar resorption.[10] Nonetheless, patients with quick progression to grade 3 were found to have significantly greater glenoid and humeral radiolucent lines.

Postoperative infection may also result in medial calcar resorption. Macrophage-driven osteolysis of the proximal humerus may result from infection and contribute to this phenomenon. While infection following primary anatomic shoulder arthroplasty is rare, low-virulence organisms such as *Cutibacterium acnes* are commonly identified in infected shoulder arthroplasties.[1,8,9,15,18]Many of these patients have minimal clinical symptoms in the setting of radiographic findings of

osteolysis.[7] It is thus possible that an under-recognized etiology of high-grade calcar resorption may also be low-grade indolent infections.

The strengths of this study include the long duration of follow-up (average of 4 years), which allowed for observation of progressive calcar resorption over time, as well as the large cohort size, which was found to have a 97.3% chance of avoidance of a type II error using a post hoc power analysis. In addition, the patients were treated with the same reproducible surgical technique and postoperative rehabilitation protocol by the same surgeon. The limitations of this study include the use of radiographs to assess glenoid loosening, which can often be difficult to observe. While analysis using computed tomography scans may have been more accurate, it is difficult to justify the additional radiation exposure required for routine radiographic follow-up. Moreover, although radiographic analysis was carried out in a standardized manner and was validated using multiple reviewers, there is the potential for differences in radiographic technique and exposure at each patient follow-up visit. In addition, significantly longer radiographic follow-up was seen in patients with progression of calcar resorption. Thus, evaluation of patients beyond 4 years may highlight a higher incidence of progression of calcar resorption, especially in the setting of progressive glenoid loosening over time. Finally, an inherent limitation in this study is the analysis of 1 specific prosthetic design, which may not be reflective of all press-fit standard-length stem designs.

Conclusion

Medial calcar resorption following TSA with a standard-length press-fit humeral component is common. Overall, no differences in PROMs or radiographic loosening were found compared with patients without calcar resorption. However, higher-grade calcar resorption and progression to more severe grades of calcar resorption should raise the suspicion of prosthetic loosening.

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References

1. Bonnevialle N, Dauzères F, Toulemonde J, Elia F, Laffosse J-M, Mansat P. Periprosthetic shoulder infection: an overview. EFORT Open Rev 2017;2:104-9. https://doi.org/10.1302/2058-5241.2.160023
2. Cooper RA, McAllister CM, Borden LS, Bauer TW. Polyethylene debris-induced osteolysis and loosening in uncemented total hip arthroplasty. A cause of late failure. J. Arthroplasty 1992;7:285-90.
3. Davis JA. Elementary survey analysis. Upper Saddle River, NJ: Prentice Hall; 1971.
4. 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. https://doi.org/10.1016/j.jse.2017.08.010
5. 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
6. 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
7. Eichinger JK, Galvin JW. Management of complications after total shoulder arthroplasty. Curr Rev Musculoskelet Med 2015;8:83-91. https://doi.org/10.1007/s12178-014-9251-x
8. Florschütz AV, Lane PD, Crosby LA. Infection after primary anatomic versus primary reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:1296-301. https://doi.org/10.1016/j.jse.2014.12.036
9. Franceschini V, Chillemi C. Periprosthetic shoulder infection. Open Orthop J 2013;7:243-9. https://doi.org/10.2174/1874325001307010243
10. Hank C, Schneider M, Achary CS, Smith L, Breusch SJ. Anatomic stem design reduces risk of thin cement mantles in primary hip replacement. Arch Orthop Trauma Surg 2010;130:17-22. https://doi.org/10.1007/s00402-009-0903-z
11. Holt G, Murnaghan C, Reilly J, Meek RMD. The biology of aseptic osteolysis. Clin Orthop Relat Res 2007;460:240-52. https://doi.org/10.1097/BLO.0b013e31804b4147
12. Inoue K, Suenaga N, Oizumi N, Yamaguchi H, Miyoshi N, Taniguchi N, et al. Humeral bone resorption after anatomic shoulder arthroplasty using an uncemented stem. J Shoulder Elbow Surg 2017;26:1984-9. https://doi.org/10.1016/j.jse.2017.04.012
13. Lazarus MD, Jensen KL, Southworth C, Matsen FA III. The radiographic evaluation of keeled and pegged glenoid component insertion. J Bone Joint Surg Am 2002;84-A:1174-82.
14. Levy JC, Berglund D, Vakharia R, Tahal DS, Mijic D, DeVito P, et al. Mid-term results of anatomic total shoulder arthroplasty with a third-generation implant. J Shoulder Elbow Surg 2019;28:698-705. https://doi.org/10.1016/j.jse.2018.08.049
15. Mattei L, Mortera S, Arrigoni C, Castoldi F. Anatomic shoulder arthroplasty: an update on indications, technique, results and complication rates. Joints 2015;3:72-7. https://doi.org/10.11138/jts/2015.3.2.072
16. 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
17. Nyffeler RW, Meyer D, Sheikh R, Koller BJ, Gerber C. The effect of cementing technique on structural fixation of pegged glenoid components in total shoulder arthroplasty. J Shoulder Elbow Surg 2006;15:106-11. https://doi.org/10.1016/j.jse.2005.05.002
18. Padegimas EM, Maltenfort M, Ramsey ML, Williams GR, Parvizi J, Namdari S. Periprosthetic shoulder infection in the United States: incidence and economic burden. J Shoulder Elbow Surg 2015;24:741-6. https://doi.org/10.1016/j.jse.2014.11.044
19. 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. https://doi.org/10.2106/JBJS.M.00378
20. 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 Surg Am 2012;94:e171. https://doi.org/10.2106/JBJS.K.00580
21. 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
22. Sanchez-Sotelo J, O'Driscoll SW, Torchia ME, Cofield RH, Rowland CM. Radiographic assessment of cemented humeral components in shoulder arthroplasty. J Shoulder Elbow Surg 2001;10:526-31.
23. Schneider CA, Rasband WS, Eliceiri KW. NIH Image to ImageJ: 25 years of image analysis. Nat Methods 2012;9:671-5.
24. 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
25. 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
26. Sperling JW, Cofield RH, O'Driscoll SW, Torchia ME, Rowland CM. Radiographic assessment of ingrowth total shoulder arthroplasty. J Shoulder Elbow Surg 2000;9:507-13.
27. Spormann C, Durchholz H, Audigé L, Flury M, Schwyzer H-K, Simmen BR, et al. Patterns of proximal humeral bone resorption after total shoulder arthroplasty with an uncemented rectangular stem. J Shoulder Elbow Surg 2014;23:1028-35. https://doi.org/10.1016/j.jse.2014.02.024
28. Triplet JJ, Everding NG, Levy JC, Moor MA. Functional internal rotation after shoulder arthroplasty: a comparison of anatomic and reverse shoulder arthroplasty. J Shoulder Elbow Surg 2015;24:867-74. https://doi.org/10.1016/j.jse.2014.10.002
29. Uschok S, Magosch P, Moe M, Lichtenberg S, Habermeyer P. Is the stemless humeral head replacement clinically and radiographically a secure equivalent to standard stem humeral head replacement in the long-term follow-up? A prospective randomized trial. J Shoulder Elbow Surg 2017;26:225-32. https://doi.org/10.1016/j.jse.2016.09.001
30. Wolff J. Concept of the law of bone remodelling, The law of bone remodelling. Berlin: Springer; 1986. p. 89-120.