

RESEARCH ARTICLE

Humeral-sided Radiographic Changes Following Reverse Total Shoulder Arthroplasty

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Abstract

Background: We sought to characterize humeral-sided radiographic changes at a minimum of 2 years after reverse shoulder arthroplasty (RSA) to determine their association with specific implantation techniques.

Methods: The immediate and most recent postoperative anteroposterior radiographs of 120 shoulders with primary RSA and a minimum of 2-years of radiographic follow-up were analyzed (mean follow-up 35.2 months). Stress shielding was evaluated by measuring cortical thickness at 4 different locations. Three independent examiners evaluated radiographs for humeral osteolysis, radiolucent lines, stress shielding, stem loosening, and scapular notching.

Results: The cortical diameter, marker of external stress shielding, significantly decreased from initial to most recent measurement ($P < 0.001$), but did not differ between cemented and uncemented groups. Cemented stems had significantly more osteolysis and radiolucent lines; uncemented stems had significantly more internal stress shielding ($P < 0.001$). The presence of scapular notching was significantly correlated with the presence of humeral osteolysis ($P < 0.001$). Three (2.5%) stems were deemed "at risk" for loosening and 2 (1.7%) were loose.

Conclusion: Cemented humeral stems were associated with an increased rate of radiolucent lines and osteolysis, whereas uncemented stems were associated with more internal stress shielding. Humeral cortical thickness significantly decreased over time regardless of fixation. There was an association between scapular notching and increased humeral osteolysis.

Level of evidence: III

Keywords: Humeral stem loosening, Osteolysis, Radiographic changes, Radiolucent line, Reverse shoulder arthroplasty, Scapular notching, Stress shielding

Introduction

Since its introduction by Grammont in 1985, reverse shoulder arthroplasty (RSA) has been successful in the treatment of cuff tear arthropathy (CTA). Although RSA was initially considered a salvage operation because of high complication and reoperation rates, more recent studies have shown good long-term survival of the implants and complication rates approaching those of anatomic total shoulder arthroplasty (aTSA) (1, 2). This

success has increased confidence in the operation, and the number of RSAs being implanted each year continues to rise (3, 4). Emerging indications for the use of RSA include massive rotator cuff tears without glenohumeral arthritis, posttraumatic sequelae, severe osteoarthritis with glenoid bone loss, proximal humeral fractures, and revision shoulder arthroplasty (5).

Most studies of RSA have focused on glenoid-sided

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radiographic changes, including radiolucent lines (RLLs), loosening, and scapular notching (1, 6). A number of reports have characterized humeral-sided radiographic changes after aTSA, but few have described humeral radiographic changes following RSA (7-17). Furthermore, specific design characteristics of RSA may make it more susceptible to humeral-sided complications than aTSA.

RSA uses a semi-constrained prosthesis, which provides the humerus a stable fulcrum for elevation in a cuff-deficient shoulder. This increase in constraint places increased torsional stress on the humeral implant, potentially leading to increased component loosening, and it may also increase volumetric wear more than traditional unconstrained shoulder arthroplasty, with the potential for particle-induced osteolysis (18, 19). Another characteristic of RSA is that it places the center of rotation distal and medial to the native glenohumeral joint, which generates an increased deltoid moment arm, as well as protects the glenoid component from increased stresses. Scapular notching from either mechanical impingement or abrasion of the humeral component on the lateral border of the scapula has been attributed to the medialized location. The clinical significance of scapular notching is unclear, but it does have the potential to generate increase polyethylene wear and wear-mediated osteolysis (19-22).

Retrieval studies following RSA have noted frequent bony impingement and abrasion in the inferior quadrant of the polyethylene components (20, 21). Day et al. found evidence of bony impingement on all inferior polyethylene rims, leading to the conclusion that impingement and edge-loading are of concern following RSA (20). Nam et al. showed that wear scores on the retrieved polyethylene components correlated strongly with glenoid radiolucency scores (21). As the polyethylene debris travels throughout the effective joint space, this has the potential to increase the amount of humeral osteolysis and RLLs as well.

Stem design in shoulder arthroplasty continues to evolve, with a shift toward uncemented implants. Few studies have compared uncemented and cemented humeral implants in RSA (16, 17). We sought to characterize the humeral-sided radiographic changes after primary cemented and uncemented RSA in patients with a minimum of 2-year clinical and radiographic follow-up.

Materials and Methods

After institutional review board approval, an institutional database was queried for all primary RSAs done between January, 2008, and December, 2014, at a large academic-affiliated private practice group. All RSAs were done by one of six fellowship-trained shoulder surgeons. Of 575 RSAs done during the six-year period, 224 had a minimum of two years of clinical follow-up. Of these, 36 RSAs were done for indications that disrupted the proximal humeral anatomy, such as proximal humeral fractures or fracture sequelae, and were excluded, and 68 patients were excluded because of incomplete or inadequate radiographs, leaving 120

shoulders with a minimum of two years of radiographic follow-up for final analysis [Figure 1]. Five different implants were used: Zimmer Trabecular Metal™ (Zimmer Biomet, Warsaw, IN), Tornier Aequalis™ (Wright, Memphis, TN), Tornier Aequalis Ascend™ Flex (Wright, Memphis, TN), DePuy DELTA XTEND™ (DePuy Synthes, Warsaw, IN), and Integra Titan™ (Integra Lifescience, Plainsboro, NJ). Standardized anteroposterior radiographs of the affected shoulder in neutral rotation obtained at the first postoperative visit and at latest follow-up were used for all radiographic analysis.

External stress shielding was evaluated by measuring cortical thickness at four different locations, two medial and two lateral, at the one-third (L1 and M1) and two-thirds junction (L2 and M2) of the humeral component as described by Nagels et al. [Figure 2] (10). Radiographic magnification was controlled by measuring the diameter of the humeral stem in each radiograph at standardized locations. This allowed calculation of a magnification factor. Correction for difference in magnification of the images was achieved by multiplying the cortical measurements by the magnification factor. All measurements were calculated by two independent examiners (one fellowship trained shoulder and elbow surgeon and one medical student), and final analysis was performed using the mean of all measurements.

Three fellowship-trained shoulder surgeons reviewed the radiographs for the presence of osteolysis, radiolucent lines, and stress shielding in seven humeral zones as classified by Gruen et al. and adapted to the shoulder by Melis et al. [Figure 3] (16, 23). Osteolysis was strictly defined as endosteal scalloping, scalloping at the bone-implant junction, or presence of cystic changes within the metaphyseal bone of the humerus. Internal stress shielding was defined as uniform regional decrease in bone density. The presence of spot welds, condensation lines, pedestal formation, scapular spurring/glenohumeral ossification, and greater tuberosity pull-off also were noted on radiographs [Figure 4]. Stem stability was assessed; stems "at risk" for loosening were identified by radiolucent lines with a width of 2 mm or more in three or more zones, and stems were classified as loose if there was a change in position (10). Finally, scapular notching was characterized according to the Sirveaux classification (6). If a disagreement among reviewers existed, the grade chosen by two of the three reviewers was used for final analysis. Disagreement between all three reviewers was not encountered.

Statistical Analysis

Because of the generally low prevalence of each radiographic finding (prevalence index, PI=0.46-0.98), inter-rater reliability (IRR) was evaluated by calculating Fleiss' Kappa, the prevalence-adjusted and bias-adjusted kappa (PABAK), and the percent agreement (24). The PABAK and the percent agreement were computed for each rater pair and averaged to provide a single index of IRR (25). IRR for notching was assessed using a two-way

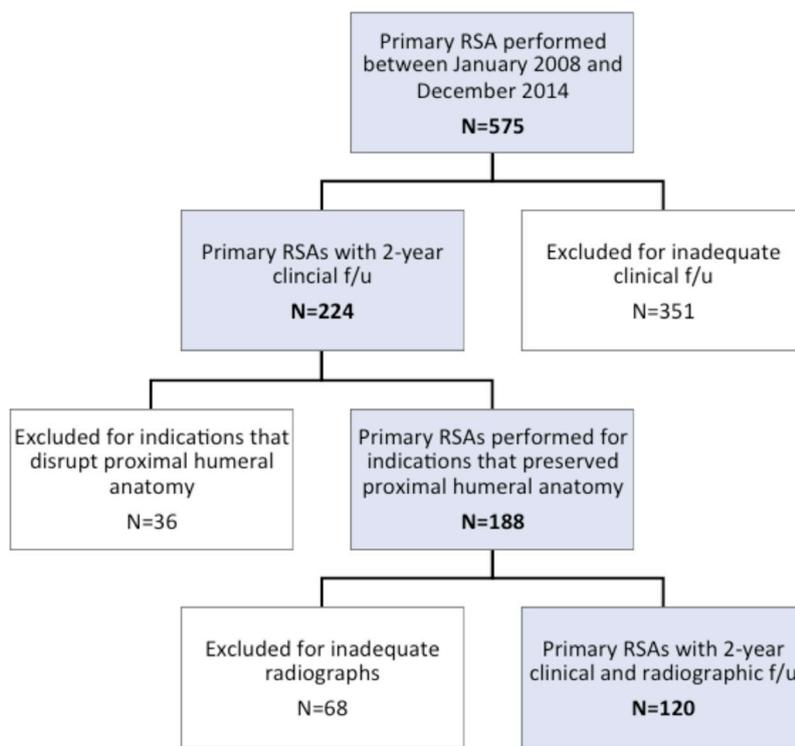


Figure 1. Inclusion and exclusion criteria.

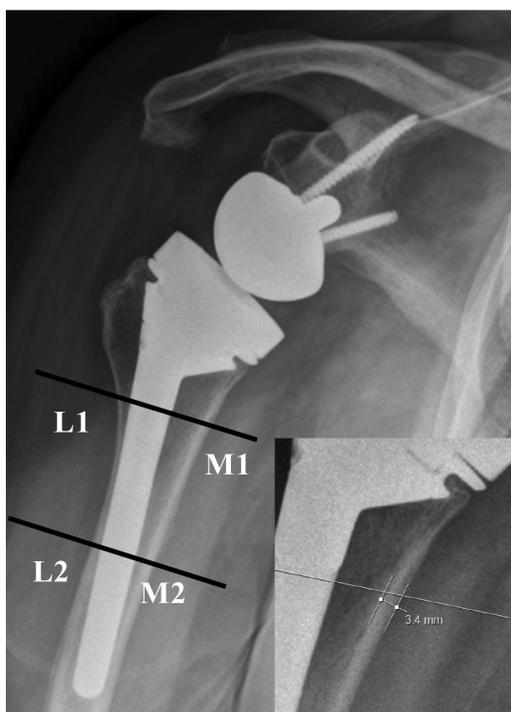


Figure 2. External stress shielding measurements as described by Nagels et al. (16).

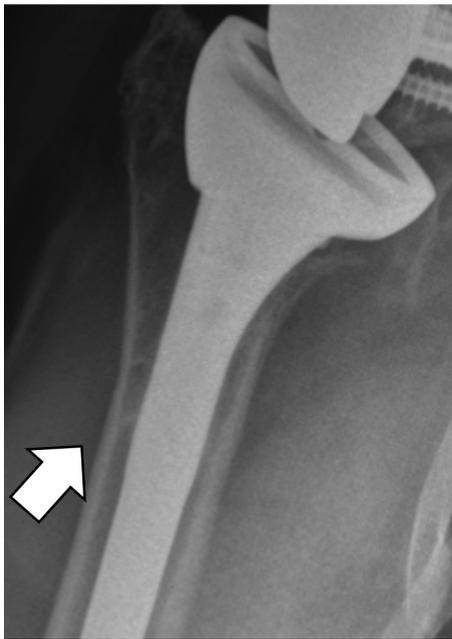


Figure 3. Radiographic zones for humeral radiographic analysis as described by Gruen et al. and adapted to the shoulder by Melis et al. (12, 15).

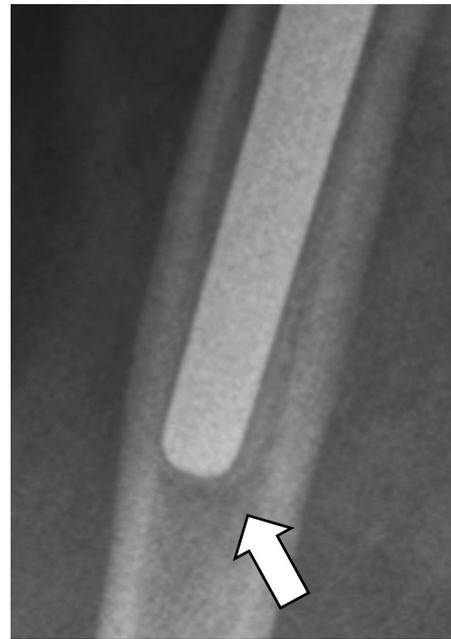
intra-class correlation (ICC) (26).

Two-way repeated measures ANOVAs tested for differences in cortical measurements (L1, L2, M1, M2) between cemented and uncemented stems over time. Pearson correlation coefficients were computed to measure the correlation between change in cortical thickness and length of follow-up and also with age. Two sample T-tests tested for differences in the change in each cortical thickness between gender. To test for

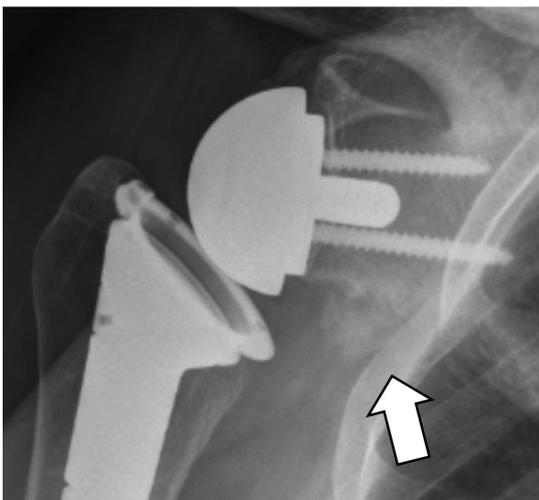
differences in the distribution of osteolysis, RLLs, and stress shielding between cemented and uncemented stems within each of the seven zones, chi-square tests or Fishers exact tests were analyzed as appropriate. Finally, Wilcoxon rank sum tests tested for differences in scapular notching grade between cemented and uncemented stems, and between stems with and without osteolysis observed, for each zone. Analyses were performed using R Statistical Computing Environment (R Foundation;



(A)



(B)



(C)



(D)

Figure 4. Representative radiographic images of spot welds (A), pedestal formation (B), scapular spurring/glenohumeral heterotopic ossification (C), and greater tuberosity pull-off (D).

Vienna, Austria).

Results

The average age at the time of surgery of the 89 females and 31 males (120 shoulders) was 70.6 years. Forty-nine humeral stems were cemented, and 71 were uncemented. Implants used were 52 DePuy DELTA XTEND™, 33 Zimmer Trabecular Metal™, 19 Tornier Aequalis™, eight Tornier Aequalis Ascend™ Flex, and eight Integra Titan™. The average length of radiographic follow-up was 35.2 months (range 24 to 107 months). Three (2.5%) of 120 shoulders were deemed to be “at risk” for loosening, and two (1.7%) were loose. All of the stems “at risk” were cemented (three of 49, 6.1%); radiographic loosening was identified in one uncemented (1.4%) and one cemented stem (2.0%).

External Stress Shielding

The cortical measurements significantly decreased from first measurement to last measurement in all locations ($P<0.001$), with average changes of -23.1% for L1, -9.4% for L2, -15.0% for M1, and -9.3% for M2. Cemented humeral stems had lower initial cortical measurements at L2, M1, and M2 ($P<0.024$) than uncemented stems, but the change in cortical thickness from the first to last measurement was not significantly different in those with cemented or uncemented stems ($P=0.237$). The length of radiographic follow-up correlated with the change in cortical thickness only at L1 for both cemented and uncemented stems ($P=0.021$). Neither age nor gender had a correlation with change in cortical thickness over time.

Osteolysis, Radiolucent Lines, and Stress Shielding

Cemented stems had significantly higher rates of osteolysis in zones 1, 6, and 7 and higher rates of RLLs in zones 2, 6, and 7 [Table 1]. Uncemented stems had significantly higher rates of stress shielding in zones 1, 2, 5, 6, and 7 [Table 1]. A higher rate of RLLs in zone 4 was seen in uncemented stems and related to pedestal formation ($P<0.001$). There was no significant difference in the presence of spot welds ($P=0.080$), greater tuberosity pull-off ($P=0.513$), or scapular spurring ($P>0.999$). Uncemented stems had more frequent pedestal formation ($P<0.001$); cemented stems had a higher rate of scapular notching ($P=0.024$). Length of follow-up did not significantly influence the presence of radiolucent lines or stress shielding, but did correlate with a higher rate of osteolysis seen in zone 6 only (41.7 m vs 33.3 m; $P=0.029$).

Presence of Scapular Notching and Osteolysis

Overall, osteolysis was present in 39 stems in zone 1 (32.5%), eight in zone 2 (6.7%), one in zone 3 (0.8%), one in zone 4 (0.8%), three in zone 5 (2.5%), 16 in zone 6 (13.3%), and 45 in zone 7 (37.5%). Scapular notching was associated with a significantly higher rate of osteolysis in zones 1 ($P=0.016$), 6 ($P<0.001$), and 7 ($P<0.001$).

Inter-rater Reliability of Radiographic Analysis

Agreement was generally high (84% to 98%) and the

resulting PABAK suggested good agreement in each zone for osteolysis (0.69-0.96), radiolucent lines (0.61-0.93), and stress shielding (0.73-0.92). The only exception was stress shielding in zone 1 which demonstrated moderate agreement (PABAK=0.53, Kappa=0.59, prevalence=0.71). PABAK also suggested good agreement between the raters for spot welds (0.96), condensation/pedestal lines (0.91), GT pull off (0.99), and scapular spur/HO (0.84). Fleiss' Kappa varied from poor (0.10 with a PI of 0.98) to excellent (0.87 with a PI of 0.56). IRR for notching was assessed using a two-way intra-class correlation (ICC). The resulting ICC was good for both agreement (0.752; 95% CI 0.704, 0.795) and consistency (0.755; 95% CI 0.707, 0.797).

Discussion

The reported rates of humeral-sided complications after RSA are low, but the frequency of complications may be underappreciated and may increase with longer follow-up (27). Our rate of humeral stem loosening of 1.7% agrees with those of previous reports ranging from 0% to 5.8% (15-17, 27-29). Interestingly, all of these “at risk” stems were cemented. Melis et al. found that 8.8% of cemented stems were loose or subsided compared to 2.9% of uncemented stems; 12% of cemented humeral stems were “at risk” compared to 6% of uncemented stems (16). Our study demonstrated an overall increase in RLLs with cemented compared to uncemented RSA in the proximally located zones 1, 6, and 7, which also agrees with the study by Melis et al. (16). In a more recent study, cemented stems were found to be a risk factor for postoperative humeral fractures, but not humeral loosening (27). It is important to note that all 15 humeral stems with aseptic loosening in this study were cemented. Since we included only the first and most recent radiographs in our analysis, progression of RLLs could not be determined and is a weakness of our study.

Stress shielding has been proposed to occur through two mechanisms. First, the solid implants used during shoulder arthroplasty have a lower modulus of elasticity than the hollow cortical bone, making them a stiffer construct. This causes a stress reduction in the proximal portion of the bone. The second mechanism relates to the rigid distal fixation of the stem in the diaphysis, which results in decreased load in the proximal portion of the bone (8). Our study showed a reduction in cortical diameter in all locations, regardless of cemented or uncemented technique. Age-related endosteal resorption could account for this reduction, but given our relatively short mean follow-up of 35.2 months, this finding supports the suggested mechanism of implant stiffness. The proximal-lateral humerus was most severely affected, as seen in a previous report (8).

Our results are similar to those of Raiss et al., who examined the radiographic changes around humeral components after hemiarthroplasty and aTSA (9). They found osteolysis in the proximal part of the humerus in 43% of patients with aTSA compared to none in patients with hemiarthroplasty; this was correlated with glenoid loosening. Overall, the rate of osteolysis of the greater

Table 1. Prevalence of osteolysis, radiolucent lines, and stress shielding in uncemented and cemented stems

Zone		Osteolysis		Radiolucent Lines			Stress Shielding		
		No	Yes	No	Yes	No	Yes		
1	Uncemented	56	15	Uncemented	70	1	Uncemented	27	44
	Cemented	25	24	Cemented	46	3	Cemented	41	8
		<i>P=0.003</i>		<i>P=0.303</i>			<i>P<0.001</i>		
2	Uncemented	66	5	Uncemented	70	1	Uncemented	40	31
	Cemented	46	3	Cemented	44	5	Cemented	45	4
		<i>P>0.999 F</i>		<i>P=0.041</i>			<i>P<0.001</i>		
3	Uncemented	70	1	Uncemented	62	9	Uncemented	61	10
	Cemented	49	0	Cemented	42	7	Cemented	47	2
		<i>P>0.999</i>		<i>P>0.999</i>			<i>P=0.120</i>		
4	Uncemented	70	1	Uncemented	27	44	Uncemented	70	1
	Cemented	49	0	Cemented	43	6	Cemented	49	0
		<i>P>0.999</i>		<i>P<0.001</i>			<i>P>0.999</i>		
5	Uncemented	70	1	Uncemented	64	7	Uncemented	62	9
	Cemented	47	2	Cemented	40	9	Cemented	49	0
		<i>P=0.566</i>		<i>P=0.283</i>			<i>P=0.010</i>		
6	Uncemented	67	4	Uncemented	69	2	Uncemented	46	25
	Cemented	37	12	Cemented	37	12	Cemented	48	1
		<i>P=0.007</i>		<i>P=0.001</i>			<i>P<0.001</i>		
7	Uncemented	55	16	Uncemented	69	2	Uncemented	30	41
	Cemented	20	29	Cemented	42	7	Cemented	47	2
		<i>P<0.001</i>		<i>P=0.031</i>			<i>P<0.001</i>		

tuberosity and/or calcar was 94.5% with a loosened glenoid component, which the authors contributed to an increase in polyethylene wear. Our study also found the proximal humerus to be most affected, with significantly increased rates of osteolysis in zones 1, 6, and 7 in shoulders with scapular notching. This may

be the result of an increase in polyethylene debris as the polyethylene component impinges against or abrades the lateral border of the scapula. This debris travels throughout the effective joint space and incites particle-induced osteolysis (19). This also may explain the increase in RLLs in zones 6 and 7 in patients with

scapular notching, as described by Melis et al (16). Although the clinical consequences remain unclear, some studies report rates of scapular notching as high as 96%, which has the potential for concern (27). We believe surgeons should be aware of the potential risks associated with scapular notching and take steps intraoperatively to avoid or reduce the frequency of scapular notching.

Several key differences were noted between uncemented and cemented stems. Stress shielding was more frequent with uncemented stems, as has been previously reported and likely is related to an increase in diameter of press-fit humeral stems, which increases stiffness and results in a decreased load on the proximal bone, leading to adjacent bone resorption (8, 16, 17). This study demonstrated an increase in pedestal formation of uncemented stems with no effect on stem stability. The clinical significance of pedestal formation is unknown. Cemented stems were shown to have increased rates of RLLs and osteolysis, which may be related to the increased frequency of scapular notching with cemented stems. Melis et al. also found an increase in RLLs in zones 6 and 7 in shoulders with scapular notching (16). Metaphyseal-fit stems that achieve stable proximal bone ingrowth may protect against wear-mediated osteolysis and RLLs (30).

Most reports regarding humeral-sided radiographic changes following RSA have focused on clinical outcomes, humeral complications, and aseptic loosening, or have been descriptive analyses of a specific implant (6, 15, 27, 28). Only two studies have compared outcomes of cemented and uncemented RSA (16, 17). We believe our study compares favorably to these because we included 120 primary RSAs for analysis, allowed only small rotational differences between radiographs, and included an evaluation of external stress shielding and the effect of scapular notching on humeral osteolysis. Finally, all radiographic analyses in the seven different humeral zones were done by three fellowship-trained shoulder surgeons with experience in critically analyzing radiographs after shoulder arthroplasty. It is important to note that one surgeon did have a relationship with industry that could be a source of potential bias.

Weaknesses of the study include the inherent limitations of a retrospective study, and the radiographic follow-up of only 35.2 months, which describes short-term humeral-sided changes. Although we attempted

to control for quality and rotational differences in radiographs, small differences can influence analysis. Our analysis included a number of different implants, and the numbers were too small to allow comparison of implants. Analysis of only the immediate postoperative and most recent radiographs did not allow comment on the progression of osteolysis, stress shielding, or RLLs. Finally, because we attempted to characterize only the radiographic changes following RSA and clinical outcomes were not included, we are unable to draw any conclusions regarding the clinical significance of the radiographic findings. Importantly, we sought to characterize the humeral-sided changes seen in a relatively large number of RSAs only.

Cemented humeral stems were associated with increased rates of radiolucent lines and osteolysis, whereas uncemented stems were associated with more stress shielding and pedestal formation. Humeral cortical thickness significantly decreased over time, with no association between cemented or uncemented stems. There was a significant association between scapular notching and an increased rate of osteolysis seen in the proximal humerus.

Declaration of conflicting interests

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