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Tribocorrosion is common but mild in modular humeral components in shoulder arthroplasty: an implant retrieval analysis

Christopher M. Brusalis, MD[a,*], Ryan R. Thacher, MD[a], Elexis Baral, BS[b], Timothy M. Wright, PhD[b], Lawrence V. Gulotta, MD[a,c], David M. Dines, MD[a,c], Russell F. Warren, MD[a,c], Michael C. Fu, MD, MHS[a,c], Samuel A. Taylor, MD[a,c]

[a]Department of Orthopaedic Surgery, Hospital for Special Surgery, New York, NY, USA
[b]Department of Biomechanics, Hospital for Special Surgery, Weill Cornell Medicine of Cornell University, New York, NY, USA
[c]Sports Medicine and Shoulder Service, Hospital for Special Surgery, New York, NY, USA

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Background: Wear and corrosion at the junctions of modular implants are increasingly recognized issues in the design of hip and knee arthroplasty prostheses, yet less is known about their significance in shoulder arthroplasty.
Methods: A query of paired total shoulder implant specimens (eg, humeral head and stem components from the same patient) was performed using an institutional implant retrieval registry. Implants were examined under a stereomicroscope and evaluated for evidence of fretting and corrosion using the modified Goldberg scoring system. Available electronic medical records of included specimens were reviewed to report relevant clinical characteristics and identify potential associations with the presence of tribocorrosion.
Results: Eighty-three paired total shoulder implant specimens, explanted at a single institution between 2013 and 2020, were analyzed. Corrosion was identified in 52% (43/83) of humeral head components and 40% (33/83) of humeral stem components. Fretting was identified in 29% (24/83) of humeral head components and 28% (23/83) of humeral stem components. Of the 56 paired implants for which clinical data were available, the duration of implantation (DOI) was less than 2 years in 29% of paired implants and greater than 5 years in 36% of implants. The presence of corrosion or fretting was not associated with DOI, a male humeral head taper, or periprosthetic infection as the indication for revision.
Conclusion: Mild tribocorrosion was present in more than half of the retrieved humeral implant specimens. However, trunnionosis did not manifest as a clinical cause of revision surgery in our study.

Implant modularity in joint arthroplasty enables intraoperative customization, but subsequent fretting wear and corrosion (termed tribocorrosion) at the interface between the modular components can limit the longevity of the joint replacement. Tribocorrosion is affected by factors such as implant design, surgical technique, and patient activity level.[1,9] Surface analyses of retrieved implants on hip and knee modular components identified tribocorrosion as a source of adverse local tissue reaction (ALTR), osteolysis, and aseptic loosening.[16] In contrast, much less is known about tribocorrosion in other joint replacements, specifically shoulder arthroplasty. Retrieval analysis literature includes only four studies comprised of relatively small cohorts of 5 to 36 implants.[2,6,8,20] Thus, the frequency of tribocorrosion in total shoulder arthroplasty (TSA) reverses total shoulder arthroplasty (RSA) components, and the specific characteristics associated with the severity of tribocorrosion remain poorly defined.

We sought to address this shortcoming by characterizing the prevalence and severity of corrosion and fretting at the taper interfaces of current modular TSA implants from multiple manufacturers. Additionally, we assessed if tribocorrosion was associated with implant design or patient demographics. We hypothesized that the rate of tribocorrosion across a large, heterogeneous sample of shoulder arthroplasty implants is relatively low in comparison with the rates of tribocorrosion reported in the existing literature pertaining to hip and knee arthroplasty studies.

Investigation performed at Hospital for Special Surgery, New York, New York, USA. Institutional Review Board approval was obtained prior to conducting the study (Study ID 2016-0094, 'Evaluation of Retrieved Joint Implant Devices.').

*Corresponding author: Christopher M. Brusalis, MD, Hospital for Special Surgery, 535 East 70th Street, 8th floor, New York, NY 10021, USA.
E-mail address: brusalisc@hss.edu (C.M. Brusalis).

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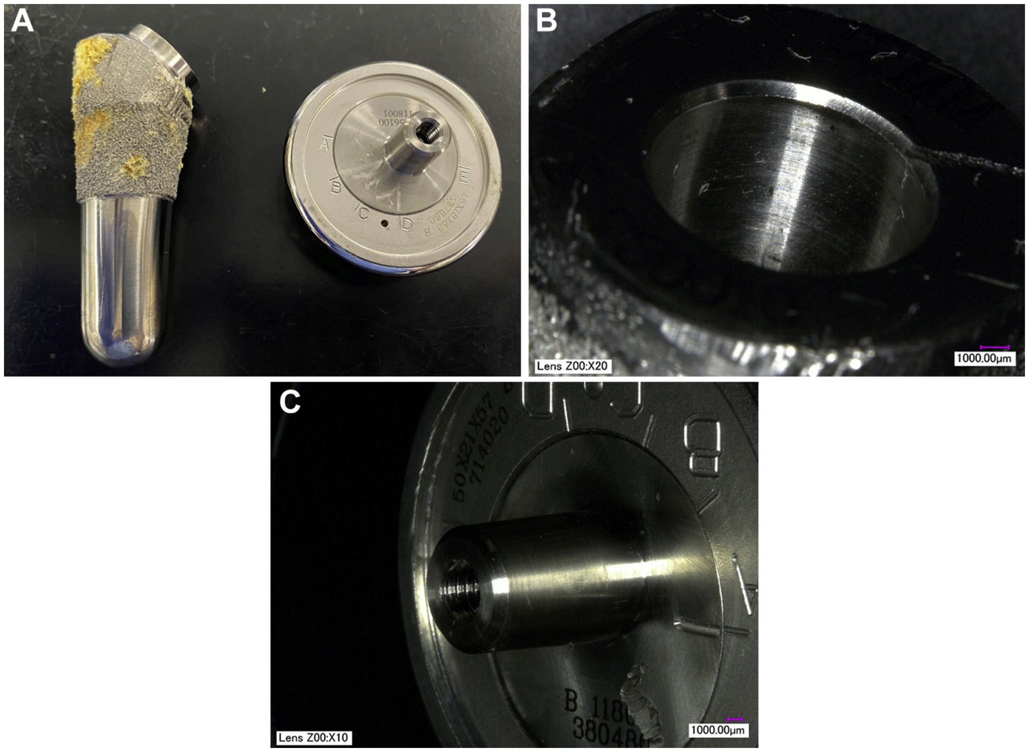

Figure 1 Example of an anatomic total shoulder specimen **(A)** with evidence of grade 2 corrosion of a female taper of a humeral stem **(B)** and male taper of a humeral head **(C)**. No fretting was identified in this paired implant.

Methods

A query of paired total shoulder implant specimens (the humeral head and stem components from the same patient) was performed from the database of an existing institutional review board-approved implant retrieval system. The query returned 83 such pairs explanted between 2013 and 2020 (Fig. 1), the period for which electronic medical records were retrievable. Seventy-eight pairs of components were of an anatomic total shoulder (TSA) arthroplasty, while 5 pairs were of reverse total shoulder (RSA) arthroplasty. The humeral implant consisted of a male head and female stem in 55 (66.5%) of the 83 specimens. Manufacturers and model types are summarized (Table I). All implant pairs were comprised of a titanium humeral stem and a cobalt-chromium humeral head.

Implants retrieved at revision surgery were placed in formalin for 3 days. Once collected from the institution's pathology department, implants were soaked in 10% bleach solution for 20 minutes and cleaned gently with soap and water, followed by drying in air. All components were then examined under a light stereomicroscope at 30× magnification (Wild Type, Herzberg, Germany) and evaluated for evidence of fretting and corrosion using a visual damage classification score as defined by Goldberg et al.[10] In this scoring system, implants are graded separately from 1 to 4 for fretting and corrosion, with a higher number representing increased presence and severity (Figs. 1 and 2). The presence of either fretting or corrosion is defined as a score >1. This subjective scoring system is the most commonly used means for quantifying tribocorrosion in arthroplasty implant retrieval analyses and has been used previously in assessing total shoulder components.[6] Two independent raters (CMB, EB) scored each specimen independently and were blinded to the patient demographics. Scoring discrepancies were resolved by re-evaluation and mutual agreement between the raters. With each implant consisting of 4 grades (humeral head fretting and corrosion, humeral stem fretting, and corrosion), discrepancies of more than 1 grade between raters were observed in only 7 of 332 grades (2.1%). Good reliability was found between the two graders in rating fretting of the humeral stem (ICC = 0.83), fretting of the humeral head (ICC = 0.85), corrosion of the humeral stem (ICC = 0.86), and corrosion of the humeral head (ICC = 0.84).

Available electronic medical records of included cases were reviewed to report relevant clinical characteristics, including patient age at the time of index surgery, patient sex, limb laterality, body mass index (BMI), indications for index and revision surgery, the type of implant (total shoulder implant vs. reverse shoulder implant), implant manufacturer, and date of implantation (DOI). Clinical data were available for 56 specimens (31 Female; 25 Male).

Table I
Retrieved total shoulder arthroplasty implants by manufacturer and model.

Manufacturer	Model	Total (n = 83) (%)
Biomet (Warsaw, IN, USA)	Comprehensive	40 (48.2)
	Comprehensive Reverse	3 (3.6)
Zimmer (Warsaw, IN, USA)	Bigliani/Flatow	8 (9.6)
	Trabecular Metal	5 (6.02)
	Select	1 (1.2)
DePuy (Warsaw, IN, USA)	Global Advantage	6 (7.2)
	Porous Shoulder	2 (2.4)
Smith & Nephew (London, UK)	Cofield 2	4 (4.8)
Exactech (Gainesville, FL, USA)	Equinoxe Primary	2 (2.4)
	Equinoxe Reverse	1 (1.2)
Tornier (Bloomington, MN, USA)	Affiniti	3 (3.6)
DJO Global (Vista, CA, USA)	DJO Anatomic	1 (1.2)
	DJO Reverse	1 (1.2)
Stryker (Kalamazoo, MI, USA)	Univers	1 (1.2)
Unspecified	-	4 (4.8)

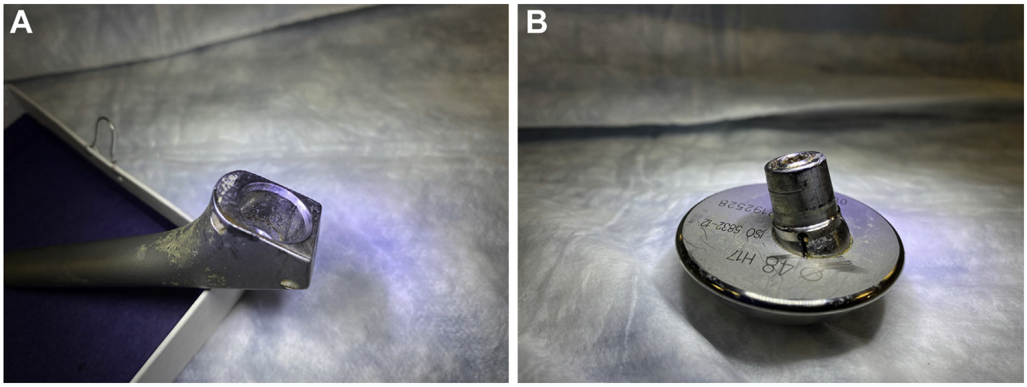

Figure 2 Example of an anatomic total shoulder specimen comprised of a female humeral stem with grade 3 corrosion, no fretting **(A)**, and a male taper of a humeral head with grade 2 corrosion and grade 3 fretting **(B)**.

The mean age was 63.6 ± 10.8 years, and the mean BMI was 29.8 ± 6.6. DOI was <2 years in 29% of the paired implants and >5 years in 36% of implants. Indications for revision surgery that led to the removal of the shoulder prostheses are listed (Table II).

Descriptive statistics were used to report demographic, clinical, and implant data. The inter-rater reliability of fretting and corrosion grading were each assessed with an intraclass correlation coefficient (ICC) for the humeral head and humeral stem. The prevalence of fretting was defined as the proportion of implants with a modified Goldberg score >1.[10] Similarly, the prevalence of corrosion was defined as the proportion of implants with a modified Goldberg score >1. Prevalence of fretting and corrosion were calculated separately for humeral heads and humeral stems. Frequencies and percentages for the number of patients with scores >1 in each of the 4 measures were computed.

To determine whether DOI was associated with the presence or severity of fretting or corrosion, DOI was categorized as less than 2 years, 2-5 years, and >5 years. Categorization was applied because, for several cases in which the index procedure was performed at an outside facility, the exact index surgery date was unknown; however, the year of index surgery was known. The Cochran Armitage trend test was employed to assess for a significant trend among increasing values of this categorical variable.

Differences between the proportions of fretting and corrosion based on the presence of a male humeral head vs. a female humeral head were assessed using a chi-squared test. Similarly, chi-squared analysis was used to identify the association of tribocorrosion with the presence of infection as the indication for revision. Statistical significance was set at $P < .05$.

Results

Corrosion was identified in 52% (43 of 83) of humeral head components and in 40% (33 of 83) of humeral stem components (Fig. 3, *A*). Fretting was identified in 29% (24 of 83) of humeral head components and in 28% (23 of 83) of humeral stem components (Fig. 3, *B*). Among humeral head prostheses, 5 had severe fretting with a grade ≥3, and a different five prostheses had severe corrosion with a grade ≥3. Among humeral stem prostheses, 2 had grades ≥3 frettings and a different 2 had grade ≥3 corrosion. No clinical cases of adverse local tissue reaction were identified.

No association was found between the DOI category and the presence of either fretting or corrosion (Table III). No difference was found between male humeral heads and female humeral heads in the prevalence of fretting in the humeral head (56% vs. 35%, $P = .25$), fretting in the humeral stem (51% vs. 24%, $P = .08$), corrosion in the humeral head (39% vs. 18%, $P = .21$), or corrosion in the humeral stem (39% vs. 29%, $P = .56$). Prostheses that had been explanted due to infection did not have significant differences in levels of fretting or corrosion of either the humeral head or humeral stem (Table IV).

Table II
Indications for explantation of shoulder arthroplasty implants.

Indication	Number (%) (n = 56)
Infection	26 (41)
Rotator cuff insufficiency	14 (25)
Unspecified pain/dysfunction	9 (16)
Aseptic loosening	5 (9)
Periprosthetic fracture	1 (2)
Instability	1 (2)

Discussion

Our study aimed to characterize the prevalence of tribocorrosion in modular humeral components across a large, heterogenous library of shoulder arthroplasty implants. The findings of this study demonstrate that failed retrieved TSA implants exhibit fretting and corrosion frequently, yet in mild forms. Additionally, we did not see differences based on the reason for revision or duration of implantation. The clinical consequences of tribocorrosion have been studied extensively in hip arthroplasty implants, particularly following complications associated with metal-on-metal total hip arthroplasty.[14] However, the frequency and significance of taper damage within shoulder arthroplasty modular components are less well characterized. Future iterations in shoulder arthroplasty design will aim to increase long-term implant survivorship and to accommodate the increased functional demands of younger, more active patients. Given the presence of fretting and corrosion observed in shoulder implant components, the minimization of taper damage at the modular humeral head-neck junction must be considered in these design efforts.

The presence of tribocorrosion found in the retrieved implants in our study resembles that reported in the few studies that have previously utilized implant retrieval analyses to evaluate shoulder arthroplasty components. Cusick et al.[6] analyzed 5 RSA implants and reported mild tribocorrosion in one implant, with none identified in the other four implants. Similarly, in our small sample of RSA implants, none demonstrated moderate or severe corrosion. Given that the RSA implant is inherently more constrained than the TSA implant, it might be expected that RSA implants are associated with higher levels of fretting and corrosion. Alternatively, an RSA implant with a larger trunnion size may reduce tribocorrosion by providing increased flexural rigidity. This unanswered question is

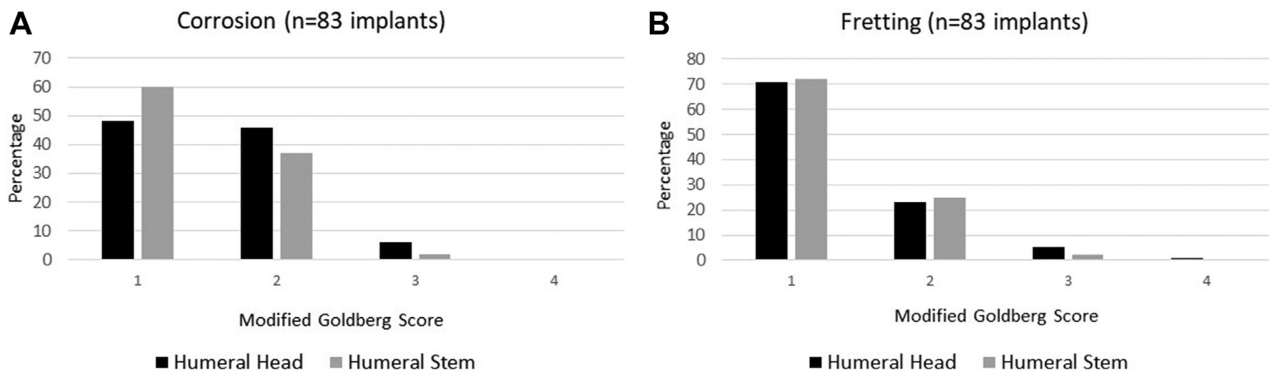

Figure 3 Distribution in the severity of corrosion **(A)** and fretting **(B)** among shoulder arthroplasty implants according to the modified Goldberg Score.[10]

Table III
Fretting and corrosion were not associated with duration of implantation.

Measure	<2 year	2-5 years	>5 years	*P* value
Head Fretting- n (%)	7 (43.8)	8 (47.1)	10 (50.0)	.709
Head Corrosion- n (%)	6 (37.5)	4 (23.5)	7 (35.0)	.919
Stem Fretting - n (%)	4 (24.0)	8 (47.1)	9 (45.0)	.243
Stem Corrosion n (%)	7 (43.8)	6 (35.3)	6 (30.0)	.396

The Cochran Armitage trend test assessed for a significant trend among increased duration of implantation, expressed as a categorical variable.

especially relevant given that RSA is typically an end-stage procedure for failed TSA and because RSA prostheses are being employed for increasingly diverse clinical indications. Further comparative studies of greater sample sizes are needed to better address this concern.

In contrast to our cohort of 83 implants, which consisted predominantly of implants manufactured by Biomet, Teeter et al.[20] evaluated 28 implants predominantly (13 of the 28) from Tornier (Bloomington, MN, USA) and identified corrosion in 32% of heads and 38% of stems. As in our study, only a few cases of moderate-to-severe tribocorrosion were identified. Eckert et al.[8] studied 36 retrieved hemiarthroplasty and TSA implants across 8 manufacturers and reported tribocorrosion in 75% of heads and 81% of stems. The study further reported a significantly higher rate of tribocorrosion among stem tapers in comparison to designs with stemless fixation.

The rates of moderate-to-severe tribocorrosion in our study and these other studies from the literature are lower than those reported in hip and knee arthroplasty implants.[12,19] In an analysis of 60 retrieved metal liners from modular dual mobility total hip implants, Hemmerling et al.[12] reporting fretting in 88% and corrosion in 97% of liners. Similarly, Spece et al.[10] found moderate to severe fretting corrosion in the majority of 166 retrieved modular knee devices. In a study of 231 modular hip implants, Goldberg et al.[10] identified moderate-to-severe corrosion at the head-neck junction in more than 40% of mixed alloy couples. Several factors may contribute to this striking difference. While the length of implantation has been demonstrated to correlate with severity of taper damage, Goldberg et al.[10] analyzed hip implants with a mean implantation time of approximately 4 years, which is similar to our cohort in which 36% of paired implants had been in use for more than 5 years. Moreover, our analysis did not identify significant differences in the prevalence of tribocorrosion based on the duration of prosthetic implantation. Instead, the relatively larger moment arm produced at the head-neck interface in hip implants, in comparison with those experienced within shoulder implants, could predispose to increased risk of tribocorrosion.[17]

Multiple factors can impact the presence and severity of corrosion of the taper at the humeral head-neck junction. When fluid, such as blood or synovial fluid, enters the space between the male and female components of the humeral head taper, metal ions from the implant can be hydrolyzed and released into the joint, a process termed crevice corrosion.[4] Modulation of bearing surfaces is thought to impact tribocorrosion. Cobalt-chrome alloy is commonly employed as the humeral head bearing surface due to its favorable wear properties, while humeral stems are often manufactured with titanium alloy given that the stiffness of titanium alloy is closer to that of cortical bone than cobalt-chrome, which minimizes stress shielding and bone resorption.[16] A recent analysis of 35 modular taper junctions of anatomic total shoulder arthroplasty implants using scanning electron microscopy demonstrated that cobalt-chromium cast alloy heads were more susceptible to fretting than heads comprised of cobalt-chromium wrought alloy.[5] Results from analyzing hip arthroplasty implants indicate that ceramic-based implants have lower rates of corrosion and fretting.[3,11,13,17] However, ceramic implants are uncommonly employed in shoulder arthroplasty due to difficulty with fabricating a sufficiently thin glenoid component.[15] Recently, improper seating of modular dual mobility liners was identified as a potential risk factor for corrosion in hip implants.[18] To date, it is unknown whether technical aspects of implantation contribute to similar findings in shoulder arthroplasty.

Notably, our analysis did not reveal a significant difference in the prevalence of tribocorrosion between implant designs with a male humeral head taper and those with a female humeral head taper. However, this comparison was performed within an intentionally heterogeneous population of implant designs that contributes as a confounding variable to this analysis. Also, increased head size has long been considered as a factor that increases the risk of corrosion at the head-neck interface.[7] More recent analysis suggested that, within hip arthroplasty, larger femoral head diameter is not associated with increased taper damage.[21] However, additional shoulder-specific biomechanical and clinical investigations are needed to confirm the extrapolations made from the hip implant literature.

This study has limitations. First, a selection bias exists that is inherent to all implant retrieval analyses, as only implants that are deemed failures are studied. Theoretically, tribocorrosion may be less common or severe among implants not requiring explanation. Second, due to the spread of implants collected that met our inclusion criteria, we were unable to match for patient variables or duration of implantation. A large, heterogeneous collection of shoulder arthroplasty implants was deliberately included to allow for more generalizable conclusions about the prevalence of tribocorrosion at the modular taper junction across all forms of shoulder arthroplasty. However, heterogeneity in surgical indication,

Table IV
Fretting and corrosion were not more prevalent in cases of periprosthetic infection.

Measure	No infection	Infection	*P* value
Head Fretting- n (%)	15 (26.8)	13 (23.2)	>.999
Head Corrosion- n (%)	9 (31.0)	9 (33.3)	>.999
Stem Fretting- n (%)	15 (51.7)	9 (33.3)	.263
Stem Corrosion- n (%)	9 (31.0)	11 (40.7)	.632

performing surgeon, implant model, bearing size precluded meaningful subanalyses regarding each variable's association with the presence of tribocorrosion. Third, full medical records were only available for the most recent subset of implant specimens, thereby introducing an additional potential selection bias. We graded all available paired specimens to accomplish the previously stated goal of establishing a larger cohort to assess the general prevalence of taper tribocorrosion. Finally, further research is needed to correlate the biological phenomenon of tribocorrosion with the clinical manifestations of trunnionosis within shoulder arthroplasty.

Conclusion

Mild tribocorrosion was present in more than half of the retrieved shoulder implant specimens. However, clinical manifestations of trunnionosis did not manifest as a clinical cause of revision surgery in our study. Future iterations in shoulder arthroplasty design, including those comprised of stemless humeral components and alternative bearing surfaces, should consider design specifications consistent with minimizing the potentially deleterious impact of tribocorrosion on shoulder implant longevity.

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Disclaimers:

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