



Contents lists available at ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Original Article

Assessment of Corrosion, Fretting, and Material Loss of Retrieved Modular Total Knee Arthroplasties

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ARTICLE INFO

Article history:

Received 12 December 2016

Received in revised form

10 February 2017

Accepted 18 February 2017

Available online xxx

Keywords:

corrosion

fretting

modularity

total knee arthroplasty

material loss

retrieval analysis

ABSTRACT

Background: Modular junctions in total hip arthroplasties have been associated with fretting, corrosion, and debris release. The purpose of this study is to analyze damage severity in total knee arthroplasties of a single design by qualitative visual assessment and quantitative material loss measurements to evaluate implant performance and patient impact via material loss.

Methods: Twenty-two modular knee retrievals of the same manufacturer were identified from an institutional review board–approved database. Junction designs included tapers with an axial screw and tapers with a radial screw. Constructs consisted of 2 metal alloys: CoCr and Ti6Al4V. Components were qualitatively scored and quantitatively measured for corrosion and fretting. Negative values represent adhered material. Statistical differences were analyzed using sign tests. Correlations were tested with a Spearman rank order test ($P < .05$).

Results: The median volumetric material loss and the maximum linear depth for the total population were -0.23 mm^3 and $5.84 \text{ }\mu\text{m}$, respectively. CoCr components in mixed metal junctions had higher maximum linear depth ($P = .007$) than corresponding Ti components. Fretting scores of Ti6Al4V alloy components in mixed metal junctions were statistically higher than the remaining groups. Taper angle did not correlate with material loss.

Conclusion: Results suggest that CoCr components in mixed metal junctions are more vulnerable to corrosion than other components, suggesting preferential corrosion when interfacing with Ti6Al4V. Overall, although corrosion was noted in this series, material loss was low, and none were revised for clinical metal-related reaction. This suggests the clinical impact from corrosion in total knee arthroplasty is low.

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The incidence of total knee arthroplasty (TKA) is on the rise. With a rate of 620,000 primary and 54,000 revision procedures per year reported in 2010 [1], TKA exceeds the rate of total hip arthroplasty (THA) procedures by >1.5 times. To meet the anatomic needs of a growing patient population and the growing demand for revision, modularity in knee arthroplasties has become increasingly popular. Modularity limits the need for an extensive inventory and facilitates intraoperative flexibility, allowing the surgeon to forego the explant of a well-fixed stem on revision.

Modular junctions, however, have been reported in the literature as areas vulnerable to degradation in THA [2–11]. Retrieval studies of modular hip arthroplasties have revealed moderate-to-severe evidence of corrosion and fretting at the head-neck and neck-stem taper junctions [2–6]. The resulting byproduct of this degradation has been reported to cause adverse local tissue reactions and the formation of pseudotumors [6–8]. Furthermore, elevated metal ion levels have been associated with adverse systemic reactions in some patients [12–14].

The study of modular interfaces in TKA is comparatively limited. Studies have reported elevated serum or plasma metal ion levels after TKA but rarely report adverse effects [15,16]. A recent case report highlighted an adverse local tissue reaction attributed to taper corrosion in TKA [17]. In response, Arnholt et al [18] performed a retrieval study analyzing qualitative corrosion and fretting severity in modular knee junctions, noting that mixed metal combinations, junction design, and component type had a

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to <http://dx.doi.org/10.1016/j.arth.2017.02.047>.

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<http://dx.doi.org/10.1016/j.arth.2017.02.047>

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Table 1
Summary of Retrievals.

Retrieval No.	Duration (mo)	Reason for Retrieval
1	0.7	Sepsis
2	13	Sepsis
3	32.4	Loose/sepsis
4	5.6	Sepsis
5	14	Pain/sepsis
6	21.2	Fracture of implant
7	30.8	Sepsis
8	40.5	Loose/sepsis
9	23	Loose/sepsis
10	59.5	Loose/bone fracture
11	27.6	Loose
12	57.3	Sepsis
13	46.2	Pain
14	68.1	Loose
15	41.9	Loose
16	74	Infection
17	11.8	Loose
18	13.2	Loose
19	77.1	Infection
20	23.8	Infection
21	67.3	Loose
22	15.3	Loose

Table 2
Assignment of Metal Combinations.

Abbreviation	Surface Analyzed	Counter Surface
Ti [Ti, Ti]	Ti alloy	Ti alloy
CoCr [Ti, CoCr]	CoCr alloy	Ti alloy
Ti [Ti, CoCr]	Ti alloy	CoCr alloy

significant effect on taper corrosion, but the impact on patient outcomes remains unclear.

The objective of the present study is to analyze changes to taper junctions in TKAs both by qualitative visual assessment and quantitative material loss measurement to assess the in vivo performance of these modular junctions.

Methods

An institutional review board–approved retrieval database was queried for all devices of a single design (NexGen; Zimmer, Warsaw, IN) with at least 1 modular junction. Devices were excluded from the study for gross retrieval artifact. A total of 22 retrievals were included. A summary of the retrievals including duration in vivo and surgeon-reported reason for retrieval is shown in Table 1. Within this set, 72 junction surfaces were evaluated representing the following 2 junction types: tapers with an axial screw (TA) and tapers with radial set screws (TR). Each of these constructs consisted of a combination of titanium (Ti6Al4V)

and cobalt chromium (CoCr) alloys. Components are denoted by their respective alloy and the junction alloy combination. A Ti6Al4V component within a mixed metal junction is denoted Ti [Ti, CoCr] and a Ti6Al4V component within a similar metal junction is denoted Ti [Ti, Ti]. These combinations are broken down in Table 2. Within the Zimmer NexGen construct, TR junctions are found exclusively on the femoral side with a CoCr female taper and a titanium alloy male taper on the stem extension. TA junctions are found on the tibial side, most commonly with a titanium alloy female taper and titanium alloy male taper on the stem extension (Fig. 1). In this series, only 1 TA junction deviated from this with a CoCr tibial tray and a titanium alloy male taper. Both axial and radial screws were made from a Ti6Al4V alloy. Sample sizes broken down by junction type and metal combination are noted in Table 3. No CoCr-on-CoCr pairings were retrieved. Each construct consisted of up to 4 components, but not all retrievals were received as full constructs.

Each surface was assessed qualitatively for corrosion and fretting via a modified Goldberg scale with 0 indicating no damage and 3 indicating severe damage (Fig. 2) [19]. These surfaces were then analyzed quantitatively for volumetric material loss (mm^3), maximum linear depth (MLD; μm), and taper angle using a coordinate measuring machine. The volumetric measurement calculated by the coordinate measuring machine accounts for both adhered material and material lost, giving an indication of the average change in volume across the surface. Here, negative values represent adhered material. Therefore, a negative volume would indicate an overall addition of material volume in the form of oxide and/or organic species across the surface. MLD reports the maximum change in depth from the surface, offering an indication of the severity of localized material loss.

The data were checked for normality using a Shapiro-Wilk test. Statistical differences of non-normal or ordinal data were determined using a paired sample sign test. Normal, continuous data were tested using a paired sample *t* test. Correlations were tested for significance using a Spearman rank order test. Statistical significance is established at $P < .05$.

Results

The devices in this series were implanted for 34.7 ± 23.5 months on average with the most common reason for retrieval being implant loosening. None of the devices were retrieved for metal-related failures.

The median corrosion and fretting scores for the full set were 2 and 1, respectively. Median corrosion scores for TR were higher than those for TA, but differences were not significant ($P = .21$). No statistical difference was determined between junction types in fretting scores ($P = 1.00$). Fretting scores for Ti [Ti, CoCr] were statistically higher than fretting scores for CoCr [Ti, CoCr] and Ti [Ti, Ti] ($P = .012$ and $P = .021$, respectively), but no statistical

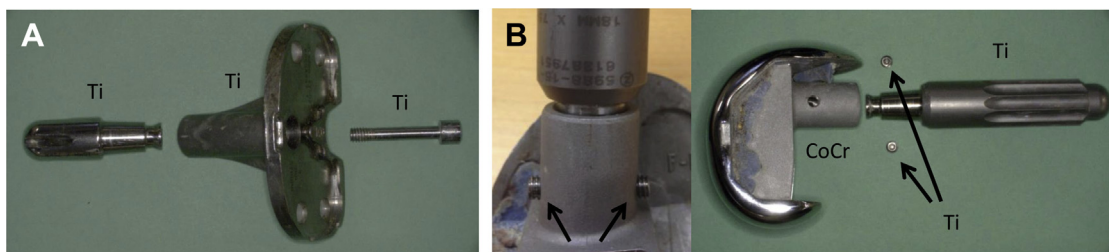


Fig. 1. Representative images of (A) a taper with an axial screw for a tibial stem extension, and (B) a taper with radial set screws (marked with arrows) for a femoral stem extension. Most commonly used material for each component is denoted.

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