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Sok Chuen Tan

Matthew G Teeter

Christopher Del Balso

James L Howard

Brent A Lanting

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Effect of Taper Design on Trunnionosis in Metal on Polyethylene Total Hip Arthroplasty

Sok Chuen Tan, MBBS, FRCS (Edin)^a, Matthew G. Teeter, PhD^{a,b,c},
Christopher Del Balso, BSc (Hons), MSc, MBBS^a,
James L. Howard, MD, MSc, FRCSC^a, Brent A. Lanting, MD, MSc, FRCSC^a

^a Division of Orthopaedic Surgery, Department of Surgery, Schulich School of Medicine & Dentistry, University of Western Ontario, London, Ontario, Canada

^b Department of Medical Biophysics, Schulich School of Medicine & Dentistry, University of Western Ontario, London, Ontario, Canada

^c Surgical Innovation Program, Lawson Health Research Institute, London, Ontario, Canada

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ABSTRACT

This study examines how taper design affects corrosion and fretting at the head trunnion surface. All hip prostheses retrieved between 1999 and 2013 with 28 mm/+0 heads were selected, resulting in 44 cobalt-chrome-on-polyethylene implants, representing six taper designs. Mean implantation time: 8.9 ± 3.7 years. The femoral head tapers were scored for fretting and corrosion using the Goldberg scale as both a combined score and by three zones (apex, central and base). There was no difference in age ($P = 0.34$), BMI ($P = 0.29$), or implantation time ($P = 0.19$) between taper groups. The 11/13 taper had the highest combined corrosion and fretting score, but no difference ($P = 0.22$) between groups for combined scores ($P = 0.22$ for corrosion, $P = 0.19$ for fretting). In a zone-specific analysis, the 11/13 taper had highest corrosion score at base zone ($P = 0.02$). Taper design had a significant effect on corrosion at base of trunnion.

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Modularity at the head–neck junction in total hip arthroplasty (THA) was introduced only in the late 1980s [1]. Prior to that, hip arthroplasty implants were of monoblock design. Modularity at the head–neck junction offers the surgeon the ability to control offset, limb length and also the option of a different head bearing material with the same stem inventory. However this modularity is not without problems.

Taper corrosion in modular total hip arthroplasty has recently been recognized to be an important issue, with multiple reports of adverse local tissue reactions even in patients with metal-on-polyethylene arthroplasty [2–10]. Cooper et al [3] reviewed ten revised metal-on-polyethylene THA that had elevated serum cobalt and chromium levels, and found visible corrosion at the head–neck junction associated with tissue necrosis and lymphocytic infiltration. Retrieval studies by Dyrkacz et al [11] and Kurtz et al [12] demonstrated significant fretting and corrosion at the head–neck taper interface in metal-on-polyethylene hip arthroplasty. Trunnionosis can therefore be a significant clinical problem.

The primary objective of this study is to examine how taper design affects the presence and magnitude of trunnionosis. The hypothesis is that there is greater trunnionosis with smaller tapers due to increased torque

force per surface area. The secondary objectives are to see if a particular zone is more prone to corrosion and fretting, and also if there is association between corrosion and fretting on the trunnion surface.

Materials and Methods

All retrieved hip prostheses from an implant retrieval lab were retrospectively reviewed after obtaining ethics board approval. These implants were retrieved over the period of 1999 to 2013. To decrease confounders, only 28 mm head diameters of plus zero length retrieved from metal on polyethylene total hip replacements were selected. All femoral heads were of cobalt–chrome alloy, and had a minimum implantation time of 2 years. This gave a total of 50 sets of retrieved implants. Models with less than three examples of each taper were subsequently excluded from analysis, leaving 44 remaining implants. Demographic details (Table 1), reasons for revision (Table 1) and prosthesis model and taper details (Table 2) were collected from the medical records. Six different tapers from four different manufacturers were included (Fig. 1).

Macroscopic and stereomicroscopic examination of the trunnion surface of 44 femoral heads was performed by two independent observers using the Goldberg damage scoring system [13] (Table 3) for fretting and corrosion. Both observers were blinded to clinical and component data where possible. An optical light microscope (Olympus SZ-STS) at $\times 40$ magnification was used to examine each surface in circumferential fashion. The visual appearance of corrosion was defined as regions of discoloration or dullness on the trunnion interface or the presence of black debris, pits or etch marks [13]. The visual appearance

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Reprint requests: Brent A. Lanting, MD, MSc, FRCSC, 339 Windermere Road, London, Ontario, Canada, N6A 5A5.

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Table 1
Demographics of Retrieved Prostheses and Reasons for Revision.

Demographics	Mean (\pm SD)
Age at time of revision (years)	69.4 (\pm 13.5)
Body mass index (kg/m ²)	29.6 (\pm 7.3)
male:female	20:24
Time in vivo (years)	8.9 (\pm 3.7)
Reason For Revision	Number
Aseptic loosening	19
Polyethylene wear	8
Periprosthetic fracture	7
Instability	2
Infection	4
Implant malposition	1
Others	3

of fretting was defined as damaged areas with small scars running perpendicular to the circumferential machine lines, or irregular flattened areas, arising from micro-motion between the surfaces [13]. Single, narrow scratches were attributed to assembly or disassembly damage [13].

Each surface of the trunnion was divided into three equal zones, the apex, central and base of the trunnion (Fig. 2). Corrosion and fretting scores were assigned to each of these zones using a scale of 1 (none) to 4 (severe), as described in Table 3. Overall scores for fretting and for corrosion were also calculated by summing the scores from all three zones.

Statistical analysis was performed with the aid of a statistician using SPSS Statistical Program version 21.0. Gaussian distribution of data was checked using Shapiro–Wilk test, and homogeneity of variance was checked using the non-parametric Levene's test. One-way ANOVA was used for comparison between the multiple groups for parametric data, and Kruskal–Wallis test was used for non-parametric data. Spearman's correlation test was used for analysis of correlation of the corrosion and fretting scores. *P* value of <0.05 was determined as the level of statistical significance.

Results

There was no demographic difference between the taper groups for age at revision (*P* = 0.343), body mass index (*P* = 0.289), or time in vivo (*P* = 0.185). Intraclass correlation coefficient between the two observers for corrosion and fretting scores was 0.993 (95% CI of 0.985 to 0.996).

There was a significant difference for corrosion within the base zone (*P* = 0.018), with the 11/13 taper having the greatest median corrosion score (Table 2). Comparison between designs for base zone corrosion is shown in Table 4. There was no significant difference between the taper types in central zone (*P* = 0.212) or apex zone (*P* = 0.839). There was also no significant difference between taper types for the sum corrosion score (*P* = 0.216), although the 11/13 taper had the highest median score of 10 (Table 2).

The 11/13 taper also had the highest median summed fretting score (Table 2), although no significant difference (*P* = 0.188) was found between tapers. There was also no significant difference between tapers

for fretting in the individual base zone (*P* = 0.100), central zone (*P* = 0.222), or apex zone (*P* = 0.137).

There was a significant correlation in the corrosion scores between all zones, including the base and central zones ($r^2 = 0.59$, $P < 0.001$), central and apex zones ($r^2 = 0.71$, $P < 0.001$) and base and apex zones ($r^2 = 0.45$, $P < 0.001$). Similar correlations were also found for the fretting scores across the various zones, including the base and central zones ($r^2 = 0.58$, $P < 0.001$); the central and apex zones ($r^2 = 0.53$, $P < 0.001$); and the apex and base zones ($r^2 = 0.59$, $P < 0.001$). However, there was no significant correlation between the sum corrosion score and sum fretting score ($r^2 = 0.24$, $P = 0.12$). No significant difference was found between the sum corrosion score and sum fretting score (*P* = 0.868).

Discussion

Early reports of trunnionosis in the literature were triggered by adverse soft-tissue reactions and early failures following metal-on-metal arthroplasty of the hip [14–16]. Some studies have demonstrated elevated blood metal ion levels in metal-on-metal THRs as compared to their resurfacing counterparts that do not have a modular head–neck junction [16–18]. Retrieval studies have shown damage at the head–neck junction with minimal wear at the bearing surface in patients who underwent revision for metal-on-metal THAs [16,19]. Corrosion at the head–neck taper junction has since been recognized to be a potential clinical concern, even in metal-on-polyethylene THAs [2,3]. Our study is the first retrieval study, to date, that examines the effect of taper design on trunnionosis in metal-on-polyethylene THA in a homogeneous group of 28 mm cobalt–chrome femoral heads.

Fretting and corrosion observed in tapers are complex issues, occurring due to the interplay of multiple physical and chemical reactions. Gilbert et al [20] described a process of mechanically assisted crevice corrosion, to explain how micromotion and mechanical loading at modular junctions disrupt a protective layer of passive oxide, resulting in crevice corrosion and fretting at the taper interface. He described that shear stresses at the taper interface cause oxide film fractures, exposing fresh metal to oxygen-rich fluid. This oxidizes the underlying metal and thereafter creates an acidic environment in the crevices, destabilizing the passive oxide film and increasing the corrosion rate. This is likely the same process occurring in the trunnions analyzed in this study. The base of the trunnion interface experiences torque forces from the hip articulation that may disrupt the oxide passivity film. The base of the trunnion also has the greatest exposure to the oxygen rich synovial fluid. In our study, taper design showed an effect on corrosion at the base of the trunnion.

Trunnion taper design has changed in recent years. Trunnions in general are becoming shorter to avoid impingement of the prosthetic neck against the acetabular component and to improve range of motion of the prosthetic joint. However what this also means is that the base of the trunnion may often sit within the inside of the taper, especially in the minus heads. This has been shown to potentiate edge loading at the trunnion base [21]. Review of these retrieved implants demonstrated a trunnion design-specific difference in corrosion at the base of the head. This coincides with this study's findings of worse corrosion at the base of the trunnion for a specific taper design.

Table 2
Classification of Various Types of Tapers and Their Corresponding Scores.

Type	Number of heads	Median Corrosion Score in Base Zone of Trunnion (Interquartile Range)	Median Sum Corrosion Score (Interquartile Range)	Median Sum Fretting Score (Interquartile Range)
Smith and Nephew 12/14 (Memphis, TN)	13	2 (2–3)	7 (6–9)	6 (4–9)
Zimmer 12/14 (Warsaw, IN)	6	2.5 (1–4)	6.5 (5–10)	7 (6–9)
Depuy 11/13 (Warsaw, IN)	3	4 (4–4)	10 (8–12)	10 (8–12)
Depuy 14/16 (Warsaw, IN)	6	2 (1–3)	6 (4–9)	4.5 (3–9)
Stryker 5 degree 38°37' (Kalamazoo, MI)	5	3 (2–4)	9 (5–12)	7 (6–12)
Stryker 2 degree 52' (Kalamazoo, MI)	11	3 (1–3)	7 (5–10)	9 (3–12)

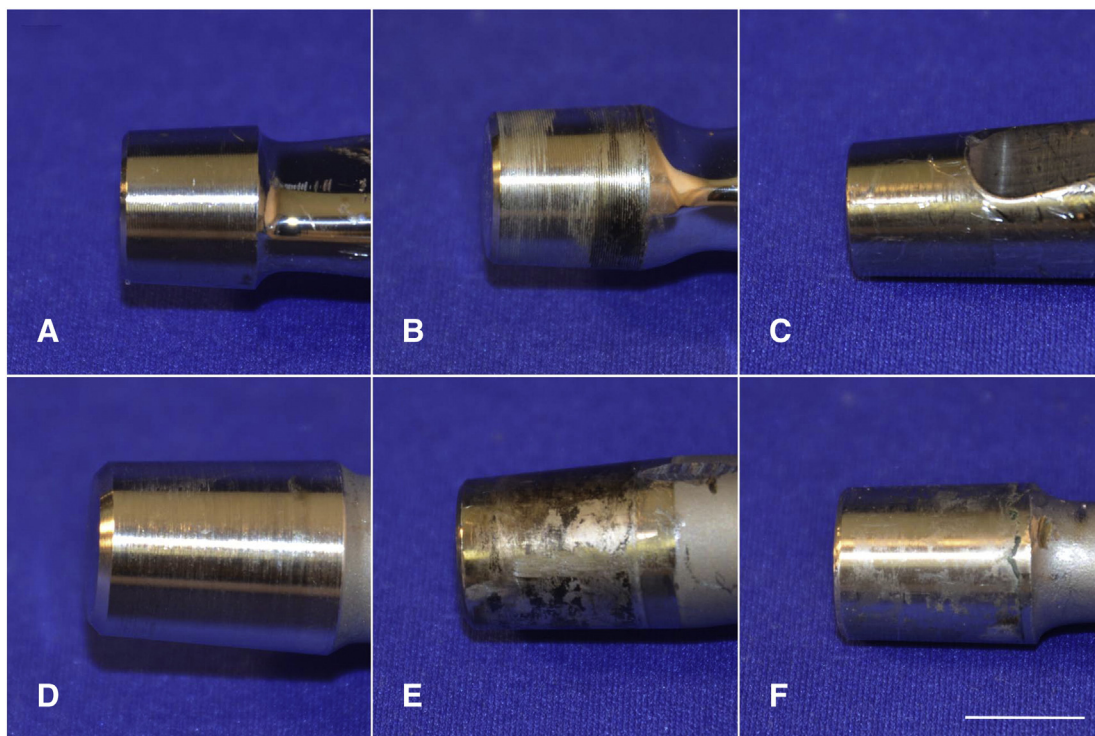


Fig. 1. Various taper designs. (A) Smith and Nephew 12/14, (B) Zimmer 12/14, (C) DePuy 11/13, (D) DePuy 14/16, (E) Stryker 5° 38'37", F: Stryker 2° 52'. Scale bar is 10 mm.

Taper–trunnion design is also becoming increasingly more narrow to increase range of movement. However a smaller taper translates to a smaller surface area and thus increases the potential for micromotion at the taper–trunnion interface. In our study, the DePuy 11/13 taper, also the narrowest type in the series, demonstrated the highest fretting score at the base zone. This could be due to a higher contact pressure from a smaller surface area. Our finding of a significant difference in corrosion score in Base zone between the various tapers is likely due to the fact that this zone is right at the rim of the head–neck interface, and thus is subjected to fluid ingress which facilitates corrosion. At this most “exterior” zone, there is also higher mechanical loading and greater torque. All these contribute to a more aggressive corrosive environment as suggested by Goldberg [13]. Recently it has also been shown that torque force rather than axial load has an implication on fretting and corrosion [22]. An additional explanation for the greatest damage to the 11/13 taper is that SROM tapers (ie DePuy 11/13 tapers) have asperities on their taper surface related to machine finishes, which could contribute to different contact length against the trunnion and therefore a different force distribution [23]. In a recent study by Porter et al [24], the 11/13 taper was also found to have the least flexural rigidity among the tapers in this study. It is known that flexural rigidity is a risk factor for corrosion as it causes micromotion due to elastic strains [13,20]. This could

be a contributory factor to the finding of a higher zonal corrosion score associated with 11/13 taper in this study.

Taper corrosion has been shown to manifest clinically as adverse local tissue reactions as shown in previous literature [2–10]. In Cooper's series [25], one patient suffered from moderate abductor necrosis due to pseudotumor formation and subsequent dislocations despite an initial revision surgery, requiring a second revision to change to a constrained liner. It is interesting to note that most of the tapers in his series were Zimmer 12/14 [25]. In Cook's series the taper type in both cases was likely Stryker V40 (from Accolade TMZF femoral stem) [2]. Lindgren's [5] case report was also on a pseudotumor from an Accolade TMZF stem. Another case report by Mao et al [6] also described a case of pseudotumor formation from a Stryker Accolade stem in a metal-on-polyethylene THA. So far, there have been no reports of clinical adverse reactions from DePuy 11/13 tapers.

This study has the limitation of small numbers of each taper design. However the study group was homogenous as it compared only 28 mm plus zero heads articulating with a polyethylene surface for a minimum of 2 years. As such, this study has the largest number in the literature to date looking at this particular question. That limited the effect of size of the femoral head or neck length affecting the torque at the taper junction. Another limitation is that the methodology to assess the extent

Table 3
Goldberg's [13] Criteria Used to Define Corrosion and Fretting.

Score	Corrosion Criteria	Fretting Criteria
1 (none)	No visible corrosion	No visible signs of fretting
2 (mild)	<30% surface discolored/dull	Band(s) for fretting scars across \leq machine lines
3 (moderate)	>30% surface discolored/dull or <10% containing black debris, pits or etch marks	Band(s) involving >3 machine lines
4 (severe)	>10% surface containing black debris, pits or etch marks	Several bands of fretting scars involving several machine lines or flattened areas with nearby fretting scars

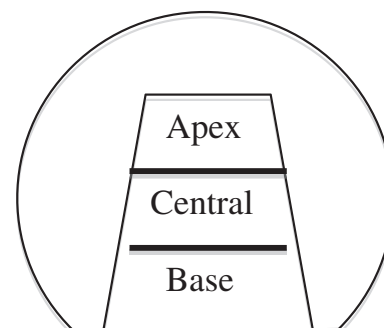


Fig. 2. The apex, central and base zones of a trunnion.

Table 4
P values of the Post-Hoc Comparison Analysis Between the Various Taper Types for Corrosion in the Base Zone.

Taper types	Smith and Nephew 12/14	Zimmer 12/14	Depuy 11/13	Depuy 14/16	Stryker 5° 38'37"	Stryker 2° 52'
Smith and Nephew 12/14		0.449	0.006 ^a	0.360	0.043 ^a	0.382
Zimmer 12/14	0.449		0.041 ^a	0.238	0.383	0.869
Depuy 11/13	0.006 ^a	0.041 ^a		0.016 ^a	0.050 ^a	0.006 ^a
Depuy 14/16	0.360	0.238	0.016 ^a		0.035 ^a	0.194
Stryker 5 degree 38'37"	0.043 ^a	0.383	0.050 ^a	0.035 ^a		0.214
Stryker 2 degree 52'	0.382	0.869	0.006 ^a	0.194	0.214	

^a Significant values.

of fretting and corrosion is subjective. However we are using a scoring system that is well recognized [13] and also shown to be correlated with material loss [26].

Trunnionosis is a clinical problem of significant controversy. In this cohort of retrieved femoral heads controlled for head dimensions and articular properties, trunnion design was found to have a significant effect on the amount of corrosion at the base of the head trunnion, with the narrowest taper 11/13 performing the worst. How the mechanical and biologic factors interact with taper design needs further review and discussion. There has been some literature implicating the effect of edge loading [27–29] and low clearance [27] on failure of metal-on-metal hip arthroplasty. The effect on metal-on-polyethylene THAs is less clear. Although in a review article by Harris et al [30], it seems that edge loading does not accelerate wear at the articulation in metal-on-polyethylene THAs, we do not yet know of its effect on the head-neck taper interface. When edge loading is coupled with certain taper designs such as one with a low taper angle, then the shear forces may be sufficiently high to manifest as clinically significant taper corrosion. This may be a question that future in vitro or large retrieval studies can answer.

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