Reduced Taper Fretting Corrosion Using a Zirconia-toughened Alumina Femoral Head in a Hip Joint Simulator Study

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Introduction: Taper fretting corrosion has been considered a potential limiting factor for total hip arthroplasty (THA) longevity. Although many studies have raised the concern of fretting corrosion, design and manufacturing process improvements have resulted in modern high-quality artificial hip joints. Moreover, several other recent studies have refocused attention on the potential adverse events that can occur because of metal debris secondary to corrosion at the taper junction [1,2]. Fretting and corrosion are considered undesirable, but their mechanism associated with soft tissue inflammatory responses is unclear.

Previously, ceramic femoral heads, mainly alumina or zirconia-toughened alumina (ZTA), have been the focus in the context of an alternative bearing surface to improve wear resistance. In fact, due to their hardness and wettability, low friction, and high wear resistance, ceramic femoral heads are suitable for use as the articulating surface in THA. However, alumina or ZTA ceramics have high chemical stability such as corrosion resistance. Several retrieval studies recently reported that metal fretting and corrosion from the head-stem neck taper may be mitigated using a ceramic femoral head [3]. However, previous retrieval studies were limited to a case study or studies with significant confounding factors.

In the study reported here, we prepared ZTA femoral heads and investigated its effects on fretting or corrosion of the head-stem neck taper under controlled laboratory conditions. Our ultimate goal in manipulating the surface and substrate of the femoral head was not just to obtain high wear resistance but also to ensure high taper fretting corrosion resistance for lifelong orthopedic bearings. In this study, we studied whether the use of ZTA femoral heads resulted in less taper fretting or corrosion than cobalt-chromium-molybdenum (Co-Cr-Mo) alloy femoral heads.

Methods: Two test groups (n = 3 per group) were total hip wear tested using a 12-station hip joint simulator (AMTI) according to ISO 14242-1. A 28-mm ZTA (Bioceram Azul; KYOCERA Medical Corp.) and Co-Cr-Mo alloy (910 metal; KYOCERA Medical Corp.) femoral heads were used for the tests. Femoral heads were attached to the hip joint simulator with a titanium-aluminum-vanadium alloy (Ti-6Al-4V) trunnion and then paired with their respective cross-linked polyethylene acetabular liners. The taper angle of the trunnion was approximately 5.5° (9/10 mm taper), which is comparable to that of the stem products (910 PerFix; KYOCERA Medical Corp.). Testing was conducted to 5 million cycles, stopping every 0.5 million cycles for interval, and bovine serum collection, and replacement. All testing was conducted in 37±2°C bovine serum with a protein content of 30 g/L as a lubricant. After the 5-million-cycle test, the femoral heads and trunnions were removed from the hip joint simulator, and were ultrasonically cleaned in ethanol, according to ISO14242-2.
The taper surfaces of the femoral heads and trunnions were inspected visually using a digital microscope for evidence of fretting and corrosion. The taper surface of the trunnion was observed on scanning electron microscopy (SEM) at an acceleration voltage of 15 kV and by energy dispersive X-ray (EDX) spectroscopy at an acceleration voltage of 15 kV. The probe size of the X-ray was maintained at 1 μm. The surface roughnesses of the contact and noncontact areas of the taper surface were measured by a stylus type surface roughness tester according to ISO7206-2.

Results: After the hip joint simulator test of 5 million cycles, the fretting and corrosion scores were lower for the taper surface of the trunnion against the ZTA femoral head than for that against the Co-Cr-Mo alloy femoral head (Figs. 1, 2). On SEM observation, machined grooves remained in the proximal taper surface (contact area) of the trunnions in both groups. Slight fretting damage was observed in those surfaces. In contrast, corrosion damage was observed in the distal taper surface (noncontact area) of the trunnion in only the Co-Cr-Mo alloy femoral head group. The corrosion damage was more severe on the medial taper surface than on the lateral taper surface. On the EDX spectra, peaks attributable to Cr, Co, Mo, and O were clearly observed in the corrosion damage region of the distal taper surface. Interestingly, the damage was hardly observed in the ZTA femoral head group. The surface roughness values (Ra) of the proximal taper surfaces of the trunnion coupled with the ZTA and Co-Cr-Mo alloy femoral heads were 0.35 and 0.28 μm, respectively, while those of the distal taper surfaces were 0.33 and 0.90 μm, respectively (Fig. 3).

Discussion: In this study, we investigated the effects of femoral head material on fretting or corrosion of the head-stem neck taper under a controlled hip joint simulator test. The ZTA femoral heads coupled with a Ti-6Al-4V alloy trunnion showed the least fretting and corrosion on the taper surface of the femoral head or trunnion. ZTA femoral heads offer the potential not only to improve long-term wear performance but also to produce a low risk of taper fretting corrosion. When used with a Ti-6Al-4V alloy stem, ZTA femoral heads also eliminate the potential for Co, Cr, and Mo ion release into local soft tissues from taper corrosion, thereby reducing the possibility of adverse local tissue inflammatory responses. In conclusion, ZTA femoral heads produce markedly less fretting corrosion compared to Co-Cr-Mo alloy femoral heads and therefore have a lower potential for metal ion release. This suggests that the ZTA femoral heads may be a promising approach to reduction risk of the taper fretting corrosion in artificial hip joints. However, we need to develop a taper system with high fretting corrosion resistance once we understand the material combination, manufacturing process, and ongoing engineering improvements.

Significance: Reducing taper fretting corrosion will increase implant survivorship and reduce complications related to metal ion-induced local soft tissue inflammatory responses. The ZTA femoral head investigated in this study demonstrated reduced taper fretting corrosion under controlled laboratory conditions against the Ti-6Al-4V alloy trunnion and may possess characteristics that optimize in vivo total hip performance.
Figure 1. Taper surface of the trunnion against the Co-Cr-Mo alloy femoral head after the hip joint simulator test of 5 million cycles. (A) Digital microscope images, (B) SEM images, and (C) EDX spectra of the taper surface.

Figure 2. Taper surface of the trunnion against the ZTA femoral head after the hip joint simulator test of 5 million cycles. (A) Digital microscope images, (B) SEM images, and (C) EDX spectra of the taper surface.
Figure 3. Arithmetic mean surface roughness of the trunnion after the hip joint simulator test of 5 million cycles. Data are expressed as means ± standard deviations. Student’s t-test, significant differences (*** p < 0.01) were observed in the comparison between proximal and distal of taper.