The Prevalence of a Column-Like Damage Pattern within CoCrMo Femoral Head Tapers

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Statement of Purpose: Corrosion of modular junctions remains a major concern for the longevity of hip replacements. Ionic and particulate corrosion products can trigger adverse local tissue reactions (ALTRs) leading to implant failure. Diverse damage modes have been shown to result in different damage patterns on head taper surfaces, including pitting, etching, and imprinting of the stem taper topography onto the head taper[1]. Another occurring damage pattern is columns of seemingly parallel troughs that run perpendicular to the initial machining marks of the surface in the proximal to distal direction. We refer to this damage pattern as column damage. Its cause is not well understood, especially since the troughs are, for the most part, not in contact with the stem taper. Previously, we have observed cells on surfaces exhibiting column damage[1]. Thus it may be possible that the presence of cells and the occurrence of column damage are related, especially when considering earlier findings by Gilbert that demonstrated cell-induced corrosion on implant surfaces[2]. In this study, we asked the following research questions: 1) What is the prevalence and extent of column damage among moderately to severely corroded head tapers? 2) Is cell-induced corrosion associated with column damage?

Methods: The study consisted of 776 retrieved CoCrMo femoral heads that had been paired against a CoCrMo or Ti-alloy stem. Corrosion damage was evaluated under a stereo-microscope and scored according to the Goldberg scale. A total of 165 retrieved heads had either moderate (n=57) or severe corrosion (n=108). The presence of global damage patterns such as imprinting and column damage was noted. Replicas of the head taper surfaces were made according to a previously described method[3] and measured with a non-contact 3D profiler (Ortholux, Redlux). Select heads were sectioned to visualize damage patterns in a scanning electron microscope (SEM).

Results: Column damage was seen in 28% of the moderately to severely corroded head tapers. Heads were coupled with a CoCrMo stem in 45% of cases with column damage, and in 21% with a Ti-alloy stem. In most cases, the extent of column damage was limited to one side of the head taper; however, in several cases the entire circumference was affected. In 91% of cases with column damage, head tapers also exhibited imprinting, whereas in the remaining 9%, column damage was so severe that no judgment could be made on the occurrence of imprinting.

3D profiler measurements showed the majority of the troughs stretched from the proximal end to the middle of the taper, and only in some cases, troughs reached all the way to the distal end of the contact area (Fig 1A). The column damage troughs exhibited no material pile-up on the sides, had an etched surface appearance (Fig 1B), and were often filled with organic residue. Imaging of a cross-section sample of column damage showed an oddly shaped trough profile with a depth of 20-40µm (Fig 1C). The surrounding microstructure showed little evidence of mechanical damage. On 3 of the 15 heads analyzed by SEM, there was evidence of preserved cells adherent to areas with column damage, but no evidence of cells adhering to corresponding stem tapers made from either Ti-alloy or cast CoCrMo alloy. The cells appeared similar to macrophages in morphology and size. Their presence was associated with an etching trail which exposed grain and twin boundaries. Cells were mainly located within the troughs, and appeared migrating from proximal to distal.

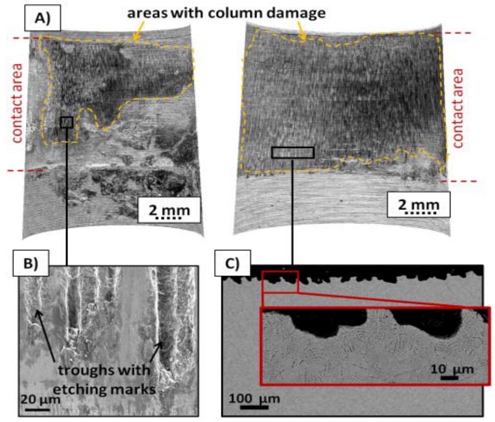

Figure 1. A) Images of two head taper replicas with partial (left) and full (right) coverage of column damage. B) SEM image of etched surface within troughs. C) Cross section image of an area with column damage.

Conclusions: These findings demonstrate that column damage is a prevalent occurrence, observed in 28% of corroded femoral heads. Column damage covered large surface areas and reached depths of 40µm, being a major contributor to material loss in head tapers, and potentially a precursor for ALTRs. The evidence suggests column damage is (electro)chemical and not mechanical, as the troughs start proximally, occur consistently independent of contact with the stem taper, and have an etched surface. A potential sequence of events might be: 1) Damage such as imprinting results in widening the crevice, enabling fluid to enter, 2) Cells such as monocytes are flushed into the crevice during daily cyclic loading, 3) Once cells reach the proximal region outside of the contact area, they attach to the surface. Alloy microstructure may play a role. The smaller grain size of wrought CoCrMo alloy may result in local surface charges that promote cell adhesion. Cell movement along the taper axis may also be related to the alloy microstructure's dependence on the drawing direction of the ingot from which heads are machined. Segregations occur if an insufficient degree of deformation was applied and may be an axial travelling path for the cells. Although there is a clear association between cell-induced corrosion and column damage, further analyses are needed to determine whether column damage is the result of cell-induced corrosion or if cells are secondarily attracted to these sites.

References: [1] Hall DJ Trans ORS 41:400, 2016 [2] Gilbert JL et al JBMR-A 103(1):211-223, 2015 [3] Cook RB et al ASTM STP1591:362, 2015