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Role of CoCrMo Alloy Banding on the Corrosion Behavior of Postmortem Retrieved Femoral Heads

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Poster 1731

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Introduction

- Total hip arthroplasty (THA) failure due to fretting and corrosion damage remains a major clinical concern
- Fretting corrosion releases implant debris from modular junctions, leading to Adverse Local Tissue Reactions (ALTRs) requiring revision surgery
- Damage to modular femoral heads can be:
  1. Mechanically dominated, i.e.-micromotion/fretting
  2. Chemically dominated, i.e.-electrochemical changes in the crevice
- Our previous work has shown chemically driven **column damage** is one of the most destructive damage modes occurring in modular junctions
  - Exhibited in **48%** of severely damaged heads[1]
  - Associated with **higher material loss** than mechanically damaged implants[1]
  - Corresponded with **increased perivascular lymphocytes** in surrounding tissue[2]
- Microstructural banding of the implant alloy provides susceptible areas for column damage to develop through severe electrochemical etching[1,3,4]
- Previous findings of microstructural banding and column damage focused on surgical retrievals, removed for adverse patient outcomes
- A well functioning, low damage control group is needed to understand the prevalence of these microstructural characteristics

PURPOSE: Determine if well-functioning femoral heads from post-mortem retrievals are less likely to exhibit banding and subsequent column damage than severely damaged surgical retrievals.

Materials & Methods

- 50 post-mortem retrieved (PMR) femoral heads were scored based on extent of damage (4: severe, 3: moderate, 2: mild, 1: none/minimal) using a modified Goldberg visually based scoring system[5]
- Two groups were defined based on damage scores (Damaged vs. Undamaged)
- Volume loss due to fretting, corrosion, and contact area between head and stem tapers was assessed with an optical coordinate measuring machine (CMM) (RedLux, OrthoLux)
  - Measurements were conducted using high resolution replicating compound (Fig. 1)

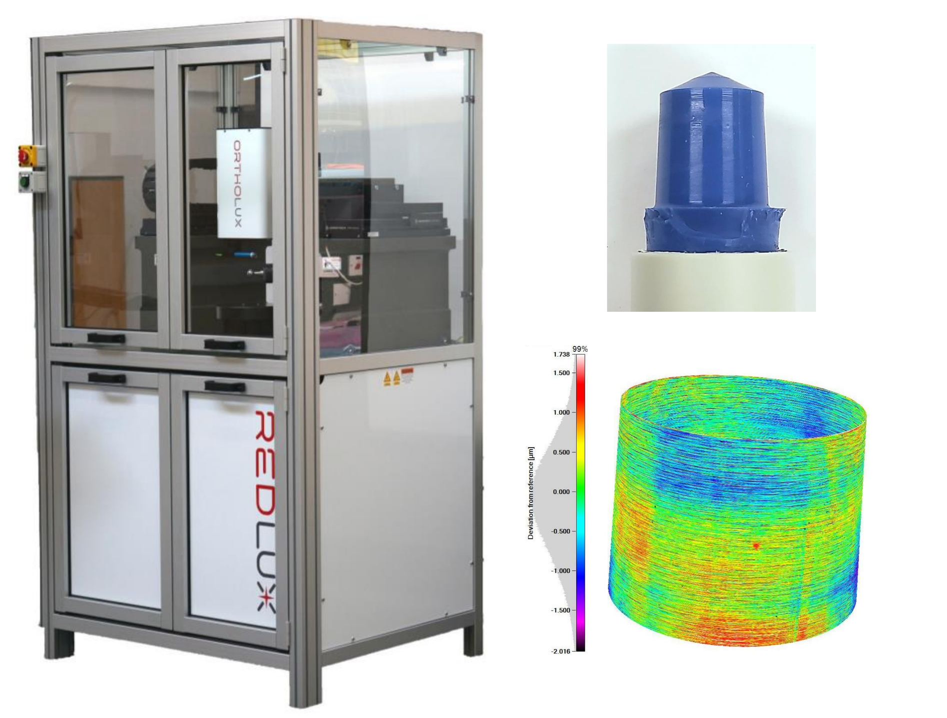

Figure 1: RedLux OrthoLux CMM[8] and Head Taper mold with corresponding heat map.

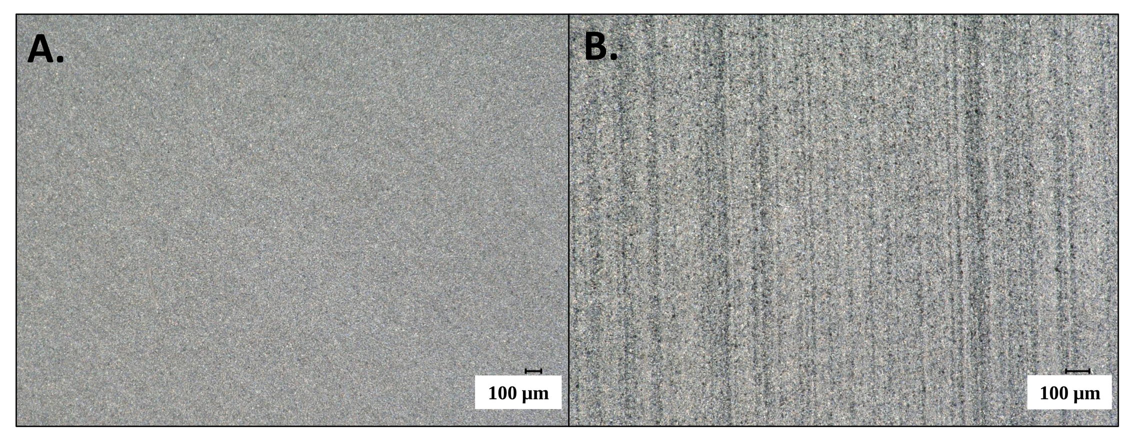

Figure 2: A) Unbanded and B) Banded Microstructure in CoCrMo Alloy Modular Femoral Heads

- Heads were sectioned along the taper axis and processed for the metallographic characterization of the alloy microstructure
- Light microscopy was used to identify banding presence in each sample (Fig. 2)
- Groups were compared using Kruskall Wallis & Mann Whitney tests (IBM SPSS 26)

Results

50 PMR Heads were scored and assigned to experimental groups with time match

Damage Score	No. of Cases	Experimental Group (n=9)
Score 1: None/Minimal	**31**	**Undamaged**
Score 2: Mild	**10**	
Score 3: Moderate	**6**	**Damaged**
Score 4: Severe	**3**	

Median material loss differed between groups (p=0.001)

- Damaged Group: 0.09mm^3 (IQ: 0.26)
- Undamaged Group: 0.00mm^3 (IQ: 0.01)
- Material loss for the three, score 4 heads: 0.27mm^3 (IQ: 0.16)

Average time in situ between groups (p=0.24)

- Damaged Group: 92.2 months (95%CI: 48.3,136.2)
- Undamaged Group: 112.0 months (95%CI: 79.4,144.7)

Banding of alloy microstructure

- Damaged Group: **78% had banding (7 of 9), 33% had column damage**
- Undamaged Group: **75% had banding (6 of 8)***

* one head excluded retroactively after discovering it was made of cast alloy

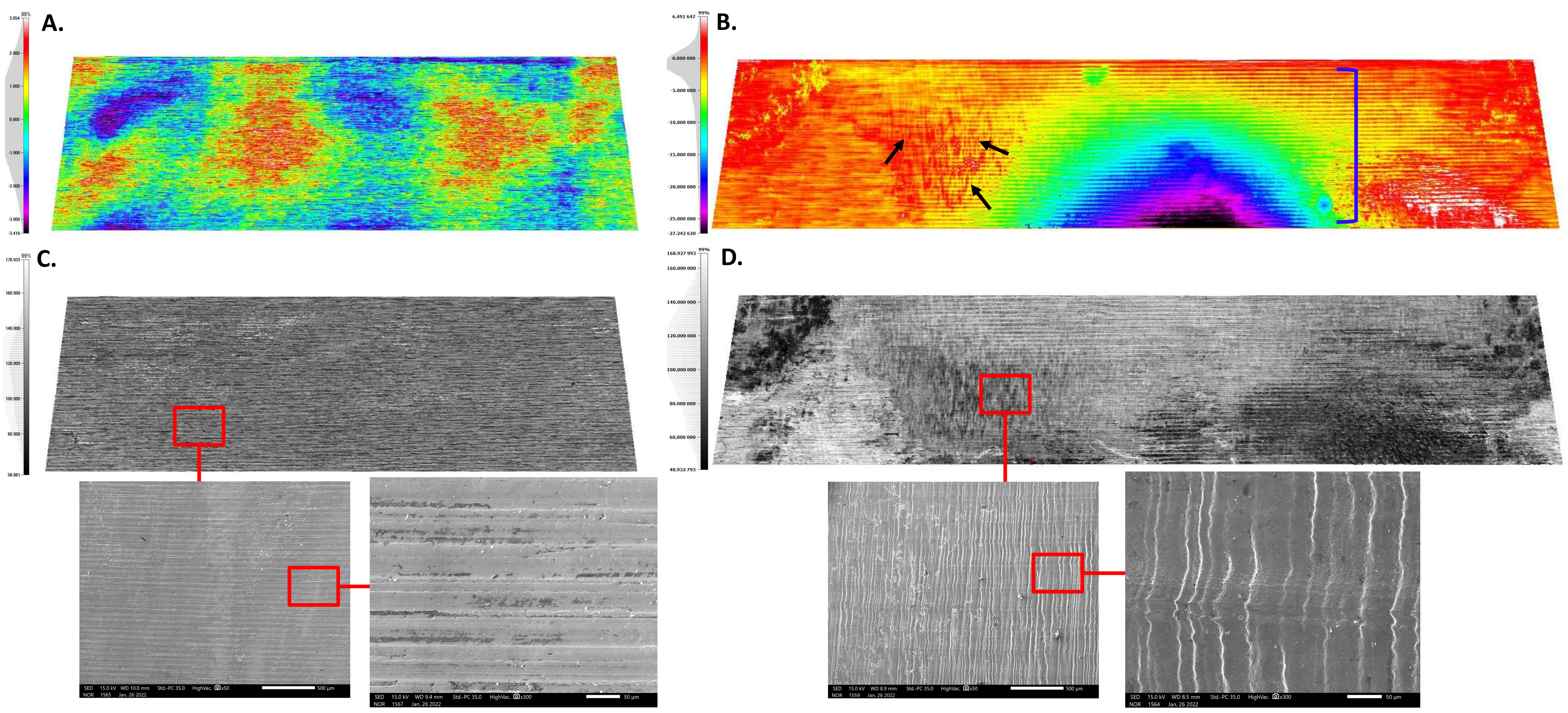

Figure 3: Heat maps (top) and intensity maps (middle) of undamaged (A & C) and damaged (B & D) PMR femoral head tapers. The undamaged head taper shows negligible damage, while the damaged head taper exhibits imprinting (blue bracket) and column damage (black arrows). Scanning electron microscopy images (bottom) of undamaged and damaged surfaces show original head taper topography and chemically induced column damage, respectively.

Discussion

- No difference was found in prevalence of microstructural banding in undamaged vs damaged PMR femoral heads
- Overall presence of banding across both groups was 76%, comparable to that observed in a large cohort of severely damaged surgically retrieved heads (81%)[1]
- Banding is a precursor to detrimental column damage; however, it does not predetermine its' occurrence or the overall performance of the femoral head
- Banding occurrence is not related to the onset of micromotion and fretting corrosion, but these initial damage types can progress to column damage if banding is present in the alloy
  - Other design factors such as surface topography, surgical assembly (e.g. assembly load), and contact area are more likely to determine the onset of the damage process[6]
- It was also shown that under progressive fretting, other chemically driven damage processes can occur such as cell-accelerated corrosion[7]
- Chemical changes within the modular junction crevice then lead to an attack on preferential corrosion sites within the CoCrMo alloy microstructure
- In wrought CoCrMo alloy, banding is the <u>most vulnerable site</u> under such conditions, leading to column damage
- A secondary finding of this study was the volumetric material loss of the damaged PMR group, specifically the severely damaged heads (0.27mm^3), was significantly lower than that of severely damaged surgically retrieved heads (1.2mm^3)[1]
- The effect of severe head damage may not always be felt due to lower corrosion product burden, as shown in this well-functioning patient group

SIGNIFICANCE: More than 25% of THR performed today rely on wrought alloy CoCrMo heads. By eliminating alloy segregation bands from the microstructure, the risk of detrimental column damage can be reduced. However, the occurrence of fretting must be mitigated by other measures, such as implant design or surgical assembly.

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Acknowledgements:
This study was funded by **NIH/NIAMS grant R01 AR070181**.

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