Fretting and Corrosion of Dual Mobility Hip Metal Liners: Role of Design, Microstructure, and Malseating

Deborah J. Hall, E. Bailey Terhune, Joseph Serino, Denis Nam, Joshua J. Jacobs, Craig J. Della Valle, Robin Pourzal
Department of Orthopedic Surgery, Rush University Medical Center, Chicago, IL

RUSH UNIVERSITY MEDICAL CENTER

The Robbins and Jacobs Family Biocompatibility and Implant Pathology Laboratory

Introduction

- The use of dual mobility (DM) total hip replacements (THR) is increasing
- Most modular DM bearings have a taper junction between a CoCrMo liner and titanium shell.
- The risk of corrosion at this interface, and potential subsequent failure due to adverse local tissue reactions remains a concern.
- The occurrence of micromotion and, ultimately, fretting and corrosion may not only be related to implant design and material factors. Additionally, surgical factors, such as malseating of the liner during intraoperative assembly.

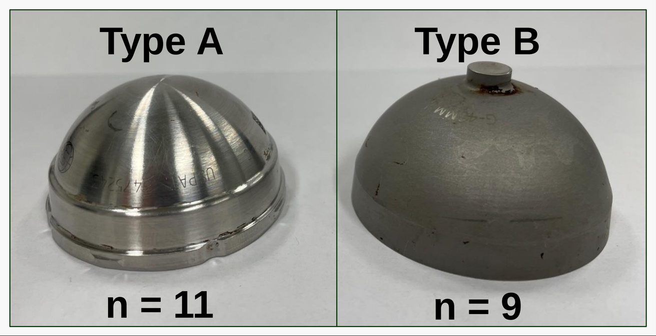
The purpose of this study is to determine the occurrence and extent of fretting corrosion on the backside of DM acetabular liners made from CoCrMo alloy by two different manufacturers in the context of design features, alloy microstructure, and malseating.

Materials and Methods

20 surgically retrieved DM acetabular liners with mean in-situ duration of 14.1 months (range 1-83) were examined

Implants

Liners from two manufacturers were evaluated



Implant Evaluation

- Prior to analysis, liners were decontaminated and cleaned.
- Using a stereo microscope at 10 to 50x, two independent graders (RP, DJH) scored each liner taper for the degree of surface damage due to fretting and corrosion based on the Goldberg score as modified by Kolz[1,2]. Consensus for a final grade was made in cases of disagreement in score.
- Scanning electron microscopy (SEM) was used to determine local damage modes based on the damage features present on tapers with moderate to severe damage. Chemical composition of deposits and films was determined by energy dispersive X-ray spectroscopy (EDS).

Modified Goldberg Score (mGS)[2]

1 = no visible corrosion
2 = mild corrosion
3 = moderate corrosion
4 = severe corrosion and fretting damage

Implant Wear and Material Evaluation

- Optical coordinate measuring machine (CMM) was used to quantitate volumetric material loss and generate heat maps to illustrate the location of fretting and corrosion damage
- One cup per manufacturer was sectioned for evaluation of grain structure and determination of the bearings' wall thickness

Radiographic Evaluation

- Malseating was evaluated by radiograph review by two observers (EBT, JS).
- Liners were considered malseated if a distinct divergence between the liner and shell was present on postoperative radiographs.

Results

Implant Features	Type A	Type B
Wall Thickness	4.1 mm	3.1 mm
Microstructure	Wrought CoCrMo	Cast CoCrMo with heat treatment after casting
Final Manufacturing Step	Machining	Roughened surface finish indicative of sand blasting

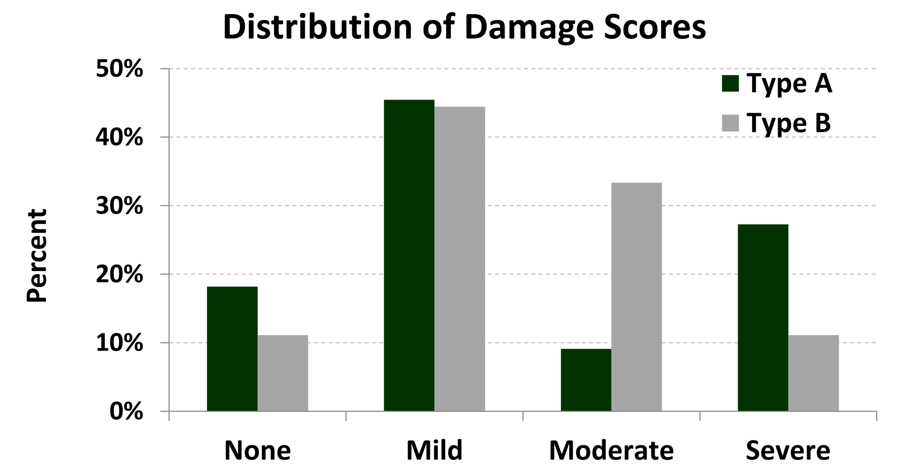


Figure 1. Percent distribution of modified Goldberg damage scores as determined by light microscopy.

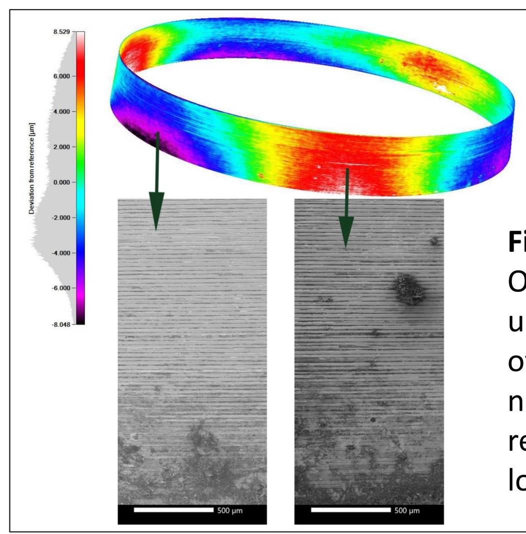


Figure 2. Heat map illustrating OOR (top) and SEM images of undamaged surface morphology of a Type A liner. Care was taken not to mistake surface depressions resulting from OOR as material loss based on SEM observations.

Type A

- **Exhibited symmetric out-of-roundness (OOR)** that appeared to originate from the machining process (e.g., clamping tool) (Fig 2)
- Local damage scars were isolated, local volume was computed, and loss from local scars was added up for a total volume loss determination (Fig 3)
- Liner A volumetric material loss at the backside occurred in 4 cases (3 with severe and 1 with moderate mGS) with an average material loss of **0.39 mm³ ± 0.22** and maximum liner penetration of **10.04 µm ± 6.77**
- Damage features on all liners of type A were consistent with fretting and fretting corrosion (Fig 4)
- One case additionally exhibited chemical etching in areas that were not in contact with the acetabular shell due to OOR
- **Five liners were malseated**, including 3 cases with severe mGS with measurable volumetric loss and 2 cases with only mild damage

Type B

- 3 of 9 liners could not be measured by CMM because these were heavily deformed during surgical removal.
- While most of the remaining liners also **exhibited OOR, these liners appeared mostly asymmetrical** and could be either a result of the casting process or deformation caused during assembly
- Type B liners also exhibited a nub at the pole for centering during seating
- SEM analysis revealed no fretting or corrosion damage features
- Damage features observed by light microscopy initially suggested the occurrence of imprinting[3] but SEM revealed these parallel lines on the surface to be organic residue with an appearance similar to that of fibrous tissue (Fig 5)
- Based on the analysis of SEM damage features, all type B liners were re-evaluated as **no or mild damage**
- **None** of the type B liners were **malseated**

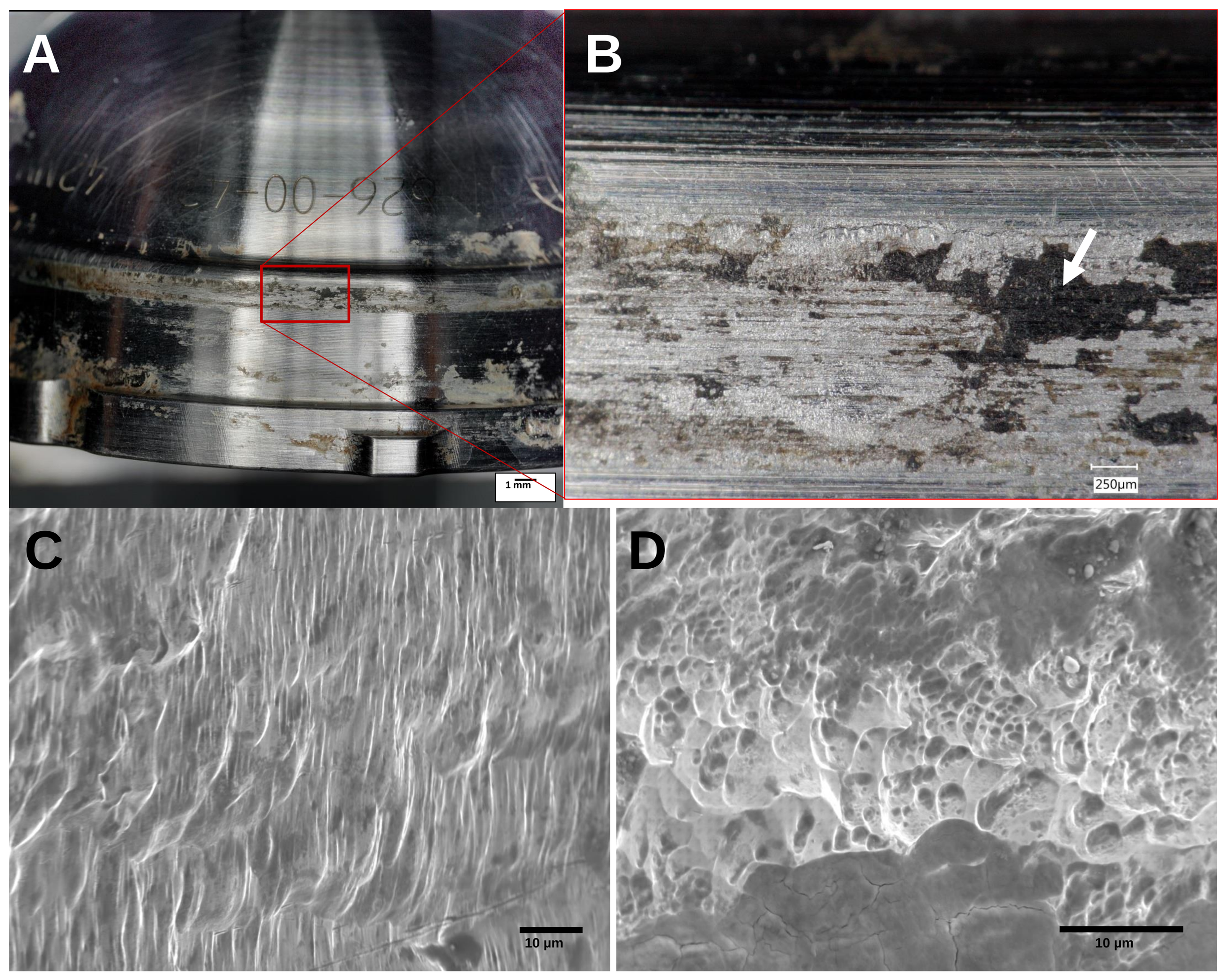


Figure 4. A: Type A liner with severe damage. **B:** Light microscopy image of damaged area (inset A). The deposits on the liner (arrow) were identified by EDS as chromium oxides. C&D: SEM micrographs of the area in B showing fretting corrosion damage (X1300, X2500).

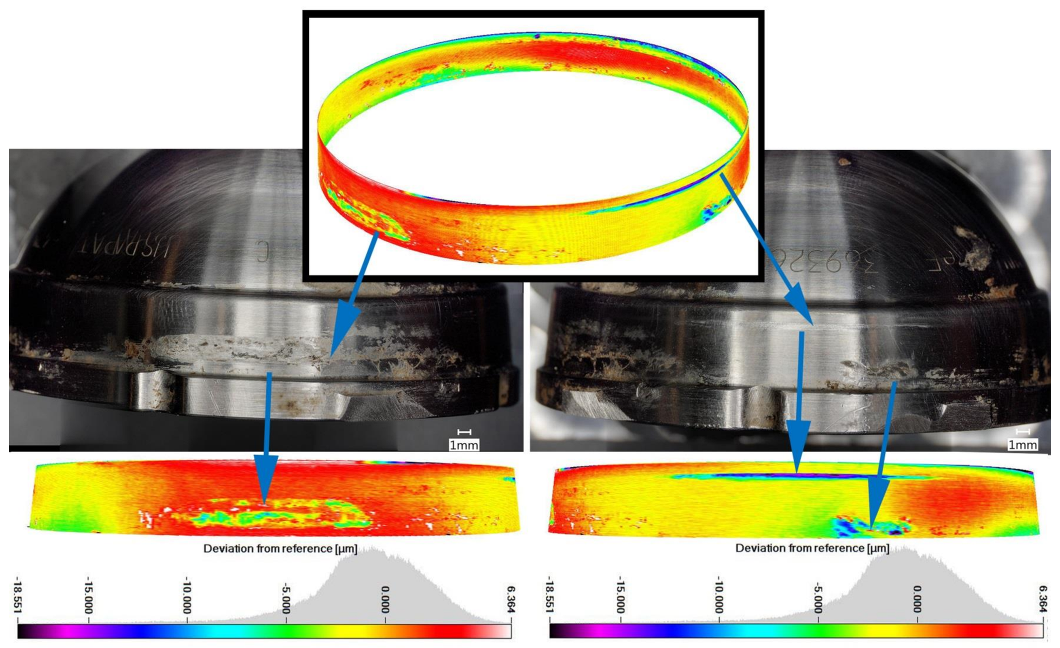


Figure 3. Heat maps (top & bottom) of a Type A liner taper surface illustrating isolated local damage scars. Total volume loss for the liner was calculated by adding volume losses from the localized areas. Material loss for this liner was 0.37 mm³.

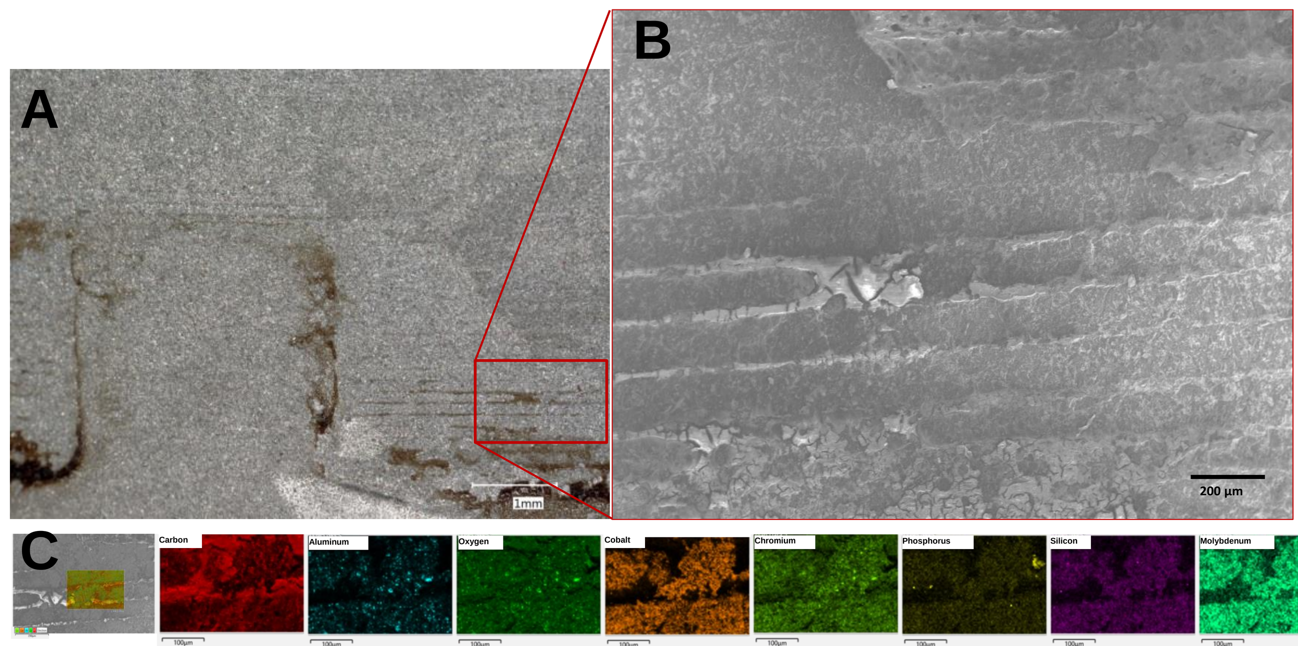


Figure 5. A: Light microscopy image of a Type B liner with damage features suggesting imprinting[3]. **B:** SEM revealed the parallel lines on the surface to be organic residue with an appearance similar to fibrous tissue. **C:** This was further confirmed by EDS analysis of this feature .

Discussion

Our study showed that different designs cannot be directly compared due to broad design, surface finish and material differences. Our findings, however, provide important insights to the corrosion performance of each individual liner type.

Type A is a sturdier liner based on design (wall thickness) and material (wrought CoCrMo has generally a higher strength compared to cast). It does not appear to deform during assembly but **exhibits mild initial OOR**.

- The combination of these factors may result in reduced contact area after seating, potentially making micromotion during patient activities more likely.
- Malseating may increase the risk of micromotion further, however, while malseated liners were associated with greater material loss, they also had a longer mean in situ duration. Thus, an independent association of malseating on liner corrosion could not be determined.
- **Fretting corrosion was observed mostly in areas that were in contact with the acetabular cup.** However, one case also exhibited chemically induced corrosion[3] in an area that was likely out of contact, indicating a chemical change within the crevice was potentially caused by cell accelerated corrosion.[4]

Type B liners **exhibited no measurable material loss**.

- Initial mGS scoring was misleading due to pseudo-imprinting features (Fig 5).
- A combination of a central nub, less wall thickness and the use of the more ductile cast alloy seems to enable a good seating and bedding-in of the liner into the cup. Plastic deformation of the cup seems to result in larger contact area and a better interference fit.
- **Both fretting corrosion and malseating were not observed in the 9 cases studied here**. The good interference fit of this liner may also explain the higher forces used by the surgeon during removal of the liner (three liners were heavily deformed). However, it may be worthwhile to examine the effect of liner deformation on the radial clearance on the bearing surface and polyethylene wear.

An important limitation of this work were the small group sizes. It is important to note that the findings here do not necessarily reflect the overall in vivo performance of these devices. Therefore, this study is ongoing to increase the groups of both liner types to confirm the observed trends, and eventually draw direct comparisons and correlations to clinical performance.

SIGNIFICANCE: The use of DM THR is rising as it provides many advantages to the patient. However, great care has to be taken that the problem of modular junction corrosion at the femoral head/neck interface is not being repeated at the acetabular liner/cup side. Fundamental knowledge of the acting corrosion mechanisms and synergistic interactions between design, material and surgical factors is essential to guarantee implant longevity.

References:
[1] Goldberg et al, CORR 2002 401:149-61; [2] Koltz et al, JOA 2020, 35:3326-29; [3] Hall et al, JBMR-B 2018, 106:1672-85]; [4] Bijukumar et al, J Orthop Res 2020, 38:393-404.

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Contact:
deborah_Hall@rush.edu