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Case Report

Early Failure of a Novel Modular Dual Mobility Liner After Metal Release: Clinical Presentation and Detailed Retrieval Analysis

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ABSTRACT

Cobalt chrome alloy (CoCrMo) corrosion and subsequent metal release has been described as a potential complication of total hip arthroplasty. Here, we present the case of a patient with a well-seated dual mobility (DM) implant revised after 10 months. Prior to revision, the patient experienced pain and stiffness. Following a negative infection workup, we measured elevated metal concentrations, hypothesized to originate from the CoCrMo DM liner. While corrosion has been extensively reported in other constructs, the CoCrMo liner described here includes a post and tabs, features added to reduce the risk of corrosion. Retrieval analysis demonstrated a severe chemically based corrosion attack on the liner. Continued caution and ongoing close monitoring of outcomes associated with the use of modular DM constructs is likely warranted.

Introduction

Like the joints they replace, metal implants degrade in vivo. However, in the hip, researchers associate cobalt chrome alloy (CoCrMo) release with adverse local tissue reactions in a subset of patients [1-3]. While metal release and subsequent biological reactions are well-accepted complications of metal-on-metal bearings, adverse local tissue response (ALTR) may also occur in modular neck and taper designs when one of the interfaces is CoCrMo [4,5]. To mitigate this risk, most surgeons now use ceramic femoral heads during primary total hip arthroplasty (THA) [6,7]. Additionally, biological reactions to metal release can have clinical ramifications, presenting as pain and instability leading to THA revision [8-12]. In rare cases, systemic effects may also occur, such as cardiomyopathy and neurologic dysfunction [4,5],[13-16]. Despite the transition from CoCrMo at the femoral-stem interface, manufacturers continue to use CoCrMo for dual mobility (DM) liners, often as a modular construct when mated with a titanium alloy (Ti-6Al-4V) acetabular component. While metal release from CoCrMo may pose increased biological risks for certain patients, long-term (>10 years) survivorship of total knee arthroplasty with CoCrMo components is high, and limited alternatives to CoCrMo exist at DM interfaces [17-19].

DM constructs have become an attractive option when pursuing THA due to their reported decreased rate of dislocation in the postoperative period, making them a desirable revision option and primary option in certain cases [20-22]. These include both anatomic monobloc and modular configurations, with a recent meta-analysis of more than 3000 patients demonstrating no difference in terms of dislocation and all-cause revision rates [23]. However, recent research has documented instances of corrosion, specifically pointing to malseating of the cup and liner interface contributing to fretting and corrosion [24-28]. To lower the risk of malseating, manufacturers are attempting to implement design features, such as antirotation tabs and polar stabilizing posts. Although these features may reduce micromotion to some degree, it remains unclear whether these new design features mitigate the risk of corrosion in DM designs, which continue to rely on CoCrMo and titanium alloy modularity.

In this case report, we present a patient with a DM THA implanted for only 10 months and revised for metal-related

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complications associated with corrosion and subsequent metal release at the modular DM liner interface. The implant studied is a novel modular DM device, which has not previously been reported on, and features a polar centralizing post and antirotation tabs which the manufacturer explicitly advertises as features designed to mitigate and address the issue of modular interface corrosion. We describe (1) the clinical presentation; (2) radiographic analysis, characterizing to what extent malseating may have occurred; and (3) retrieval analysis of the explant investigating the structurally and chemically based processes leading to in vivo metal release.

Case history

Signed, informed consent as well as institutional review board approval were obtained. A 56-year-old female presented to our clinic in July 2024 with complaints of painful hips in the setting of prior bilateral primary THA performed at an outside institution for osteoarthritis, with right greater than left pain. She presented with bilateral groin pain and right hip stiffness, also noting that her right hip was consistently painful since surgery. She did not report any start-up pain, gait abnormalities, or subjective weakness or limits to range of motion. The prior surgeon has performed the THA by means of a direct superior approach. She had her left THA placed in January 2023 with a titanium stem (Origin Stem, Enovis, Wilmington, DE), a polished stainless steel nonmodular 1 piece acetabular component with a porous titanium spray and hydroxyapatite ingrowth surface (Novae SunFit TH, Omnilife Science, now Stryker, Mahwah, NJ), and a +3.5 28-mm Delta ceramic (Biolox Delta, CeramTec for Enovis, Wilmington, DE) inner and 49-mm polyethylene outer (Omnilife Science, now Stryker, Mahwah, NJ) DM head. While she had some pain and symptoms with this hip, they were mild at the time of initial presentation. She subsequently had her right THA placed in November 2023 with a titanium stem (Origin Stem, Enovis, Wilmington, DE), a 50-mm hemispherical titanium alloy acetabular component (Empowr, Enovis, Wilmington, DE) and a 40-mm modular CoCrMo liner (Empowr Dual Mobility, Enovis, Wilmington, DE), and a +3.5 28-mm delta ceramic (Biolox Delta, CeramTec) inner and 40-mm polyethylene (Empowr Dual Mobility Polyethylene) outer head. The patient presented to our clinic for second opinion regarding the persistent symptoms in both hips, although her primary complaint was of the right hip.

Her examination was notable for a painful right hip with resisted flexion and stiffness, while her left hip demonstrated tenderness to palpation at the greater trochanter and in her groin. She had no loss of range of motion and no weakness on examination. The right hip was more symptomatic of the 2. Radiographs (Fig. 1) demonstrated well-fixed and well-positioned femoral and acetabular implants. The right hip demonstrated what appeared to be a well-aligned and seated modular DM liner within the acetabular component, and no other notable or concerning findings. The left hip demonstrated a slightly lateralized monolithic acetabular shell with some overhang at the anterior acetabular rim which was thought to be causing some psoas tendon impingement which could account for the groin-based symptoms on the left. She had no other joint replacements or orthopaedic implants in her body.

Given the significant symptoms and unconcerning plain imaging of the right hip, additional workup was deemed appropriate. Serum laboratory tests were sent for infection workup, and due to the presence of the modular CoCrMo liner in the right hip being the only source of CoCrMo, cobalt (Co) and chromium (Cr) metal ions were also sent. Results showed no concern for infection, with a normal white blood cell count of 4.86×10^9/L, an erythrocyte sedimentation rate of 7 mm/h, and C-reactive protein of 0.1 mg/dL. However, serum Co and Cr concentrations were found to be elevated at 7.1 μg/L and 1.4 μg/L, respectively. Cross-sectional imaging with a metal-suppressed magnetic resonance imaging was performed which showed a small effusion. An aspiration was attempted under ultrasound guidance to obtain synovial metal ions to verify the source of elevated serum ions, but this effort resulted in a dry tap.

Given the lack of other sources of CoCrMo in the body, and the elevated Co and Cr concentrations, and even more specifically an elevation of Co greater than Cr (a ratio which has been found to be associated with taper corrosion in THA [29,30]), the patient was diagnosed with metal-related complications in the DM construct of her right THA. It was believed that the etiology was associated with metal release from the CoCrMo-titanium alloy modular DM taper, accounting for the patient's symptoms. Subsequently, the patient was booked for a head and liner exchange.

Our patient underwent revision surgery in September 2024. Her hip was accessed using a modified Heuter approach. During exposure of the components, it was noted that there was abundant soft tissue around the acetabulum, a capsule thickened to at least 3 times its typical thickness, and a thin soft tissue membrane inside the cup itself. The surrounding soft tissues did not demonstrate metallic or colored staining.

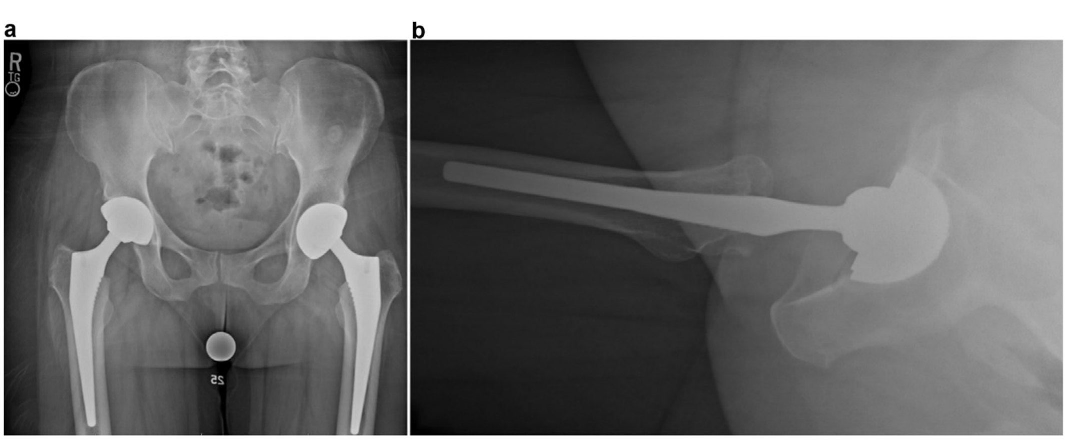

Figure 1. Prerevision surgery (a) anteroposterior and (b) lateral radiographs of the right hip without evidence of significant component compromise or loosening.

The CoCrMo liner appeared to be well seated. There were no acetabular screws present, so there was no sign of screw head or screw hole impingement. After removal of the liner with an impact tool on the rim of the shell, the liner was dissociated from the Ti cup. Gross visual inspection at the time of removal demonstrated signs that appeared consistent with corrosion (Fig. 2). The patient was exchanged to a new 36-mm ceramic head (Biolox Delta, CeramTec for Enovis, Wilmington, DE) and modular highly cross-linked polyethylene liner (Empowr 36E Liner, Enovis, Wilmington, DE), with retention of the femoral stem and acetabular cup. There were no intraoperative complications with postoperative radiographs demonstrating appropriate placement and alignment of components (Fig. 3). The patient was discharged home on postoperative day 1.

The patient was seen in clinic for follow-up approximately 3.5 weeks after surgery. She reported significant, and near immediate, improvement in her right hip pain as well as some improvement in her left hip pain. Anaerobic and aerobic cultures from her revision surgery were noted to be negative at this time. Pathologic analysis of the soft tissue collected at the time of surgery demonstrated synovial tissue with fibrosis and local inflammation and an aseptic lymphocyte-dominant vasculitis-associated lesion (ALVAL) score using the standard method of 1 for synovial lining, 1 for inflammation, and 2 for tissue organization [31]. She was subsequently seen at approximately 8 weeks postoperatively and reported continued improvement in her right hip pain. She was seen again approximately 3 months after surgery and had continued improvement in her right hip pain. Postoperative metal ions were obtained approximately 5 months after revision and were found to be nondetectable, with values less than our laboratories' (ARUP Laboratories, Salt Lake City, UT) detectable reporting limits at < 1.0 μg/L.

Retrieval analysis

Digital images of the retrieved CoCrMo liner show top (Fig. 4a) and side (Fig. 4b) views before cleaning. Note the severe corrosion where the CoCrMo liner contacted the Ti-6Al-4V acetabular component in vivo. At 30x magnification (Fig. 4c, after cleaning, Keyence VHX-7000, Keyence Corp., Itasca, Illinois), horizontal machined lines become visible. An undamaged area exists between the locking tab and the corroded interface. Measurements of the vertical distance between these 2 features (ΔTab-Corrosion) reveal a uniform undamaged region around the liner's circumference (Fig. 4d). We measured a minimum distance of 1.6 mm and a maximum distance of 1.75 mm. These data suggest a well-aligned liner with visually indistinguishable differences at each of the locking tabs. While the contact between modular components began at a homogenous height, 1.7 ± 0.05 mm from the locking tabs, within the regions themselves, contact is clearly nonuniform. Here, contact likely initiated at the local maxima on the manufactured surfaces and progressed heterogeneously during degradation processes, generating a surface where some areas appear corroded and others do not.

Figure 2. Explanted CoCrMo liner with a polar centralizing post and macroscopically visible dark corrosion products at and around the equatorial locking taper. CoCrMo, cobalt chrome alloy.

Degradation began and ended in clearly defined visual bands on the taper, likely governed by device geometry, but damage appears heterogenous inside those bands (Fig. 5A). Black oxide debris, column damage, and plastic deformation occur near one another. A digital image acquired at 100x magnification (Fig. 5b) identifies vertical trough-like features, which are characteristic of column damage. At the base of the tapered region, the CoCrMo alloy has an oil spill—like appearance (Fig. 5c), indicating structural changes to the passive oxide film. Within the corroded interface, in an area like Figure 4c, the CoCrMo alloy appears burnished with elongated ovals (Fig. 5d), consistent with mechanically assisted crevice corrosion (MACC).

The tapered area of the liner's back side was scanned with an optical coordinate measuring machine (OrthoLux, RedLux, Romsey, United Kingdom). The resulting intensity map (Fig. 6, top) shows a 3-dimensional view of the corroded interface. The black and dark gray regions correspond with oxide debris and column damage regions, respectively. Features on the corroded region (Fig. 6, middle) mirror the digital images in Figures 4b and 5a. A heat map was generated after cone fitting of the undamaged areas showing intact machining lines (Fig. 6, bottom). It reveals that areas with column damage deviated the most from the reference, appearing black and purple. Across the corroded DM liner interface, we measured 0.76 ± 0.03 mm^3 of material loss. This exceeds the maximum material loss values (≤ 0.6 mm^3) previously published in the literature for malseated DM liners [4].

Scanning electron microscopy (Apreo 2S Lo Vac, Thermo Fisher Scientific, Waltham, Massachusetts) definitively demonstrates the damage modes identified using digital optical microscopy, including MACC (Fig. 7). Paired secondary (Fig. 7a) and backscattered electron micrographs (Fig. 7b) show plastically deformed machine lines. In between, a chemically based corrosion attack dominates (ie, the crevice corrosion processes of the MACC mechanism). The diameters of the oval-like features vary, and in some cases, they interconnect (Fig. 7c). At 15,000x magnification (Fig. 7d), surface features and structural changes become visible. The bulk alloy contrasts with the edges of the ovals, which appear speckled. From secondary imaging alone, it is unclear if the contrast is due to organic or oxide debris. Additional debris collects at the bottom of each oval.

We documented column damage on the retrieved liner, ranging from mild (Fig. 8), to moderate (Fig. 9) to severe (Fig. 10). Faint vertical troughs initiate near MACC (Fig. 8a). This is most easily seen in a plastically deformed machine line, cleaved in 2 (Fig. 8b). Note the cluster of equiaxed pits in the bottom-middle of the micrograph, visually distinct from the burnished and elongated ovals (top of the micrograph). In the column features (Fig. 8c), intragranular corrosion initiates, degrading the grain boundaries. Within the troughs, individual grains appear etched (Fig. 8d). At 5000x

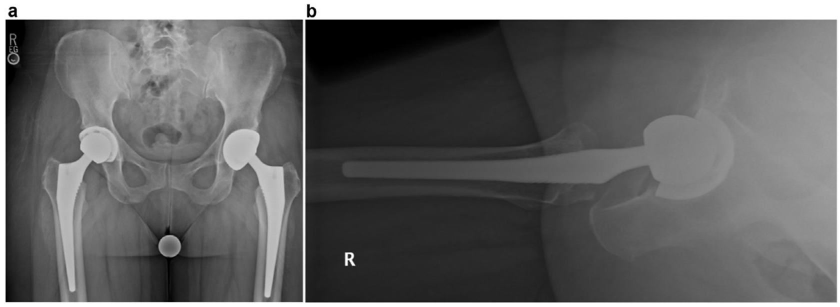

Figure 3. Postoperative (a) anteroposterior and (b) lateral radiographs of the right hip demonstrating appropriate placement of components without evidence of complication.

magnification, both surfaces (Fig. 8c and d) look burnished, suggesting mechanical interruption of the passive oxide film.

On areas of the liner with moderate column damage (Fig. 9a), the bimodal corrosion mechanism becomes clearer. The vertical troughs and columns visually contrast, and plastically deformed machine lines intersect horizontally. The CoCrMo grain boundaries dissolved from the surface of the columns (Fig. 9b). However, the wrought grains of the substrate alloy appear comparatively uncorroded. In contrast, within the troughs, degradation of the grains seems to be the leading edge of the corrosion attack, leading to comparatively more material loss. Thus, 2 selective dissolution processes simultaneously occur: (1) intragranular corrosion dominates on the columns (Fig. 9c) and (2) etching promotes degradation of the troughs (Fig. 9d). At 10,000x magnification, a backscattered electron (BSE) micrograph shows etching of individual wrought CoCrMo grains (Fig. 9e). A lattice structure is left behind, evidence of the selective dissolution (Fig. 9f).

On regions exhibiting severe column damage, we observed a complete breakdown of the horizontal machine lines (Fig. 10a). Troughs and columns stretch continuously across the surface as contrasting vertical bands (Fig. 10b). Corrosion again appears bimodal. In the columns, the crevice corrosion attack degrades the remaining wrought grains (Fig. 10c). Although etch marks remain visible in the troughs, pitting now drives the chemically based corrosion attack. A secondary micrograph acquired at 5000x (Fig. 10d) reveals how intragranular corrosion on the troughs may progress to a more general corrosion attack. Large (>5 μm) voids intersperse between degraded wrought grains. Grains may have dissolved or fallen from the microstructure following severe intragranular corrosion.

Micrographs reveal a pitting corrosion attack (Fig. 11). Pit diameters varied ranging from >5 μm (Fig. 11a) to submicron and smaller (Fig. 11b). Backscattered electron images show how pits may nucleate, grow, and interconnect (Fig. 11c-d). In all 4

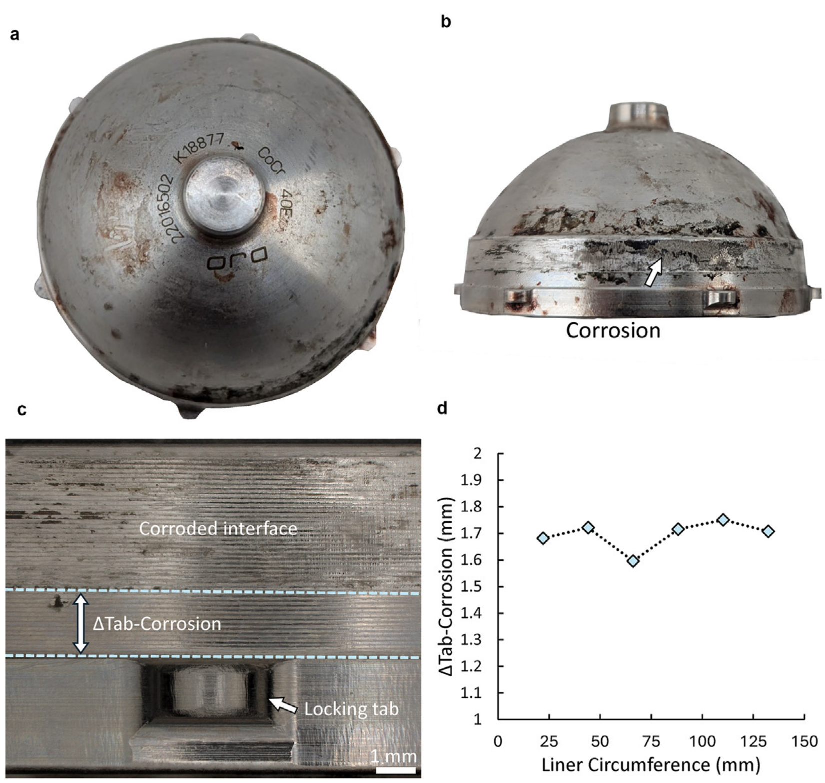

Figure 4. Digital images show a (a) top and (b) side view of a corroded CoCrMo liner. (c) Corrosion initiated at a fixed distance above the locking tab. (d) We measured a uniform distance across the circumference of the liner, indicating a well-aligned device in vivo. CoCrMo, cobalt chrome alloy.

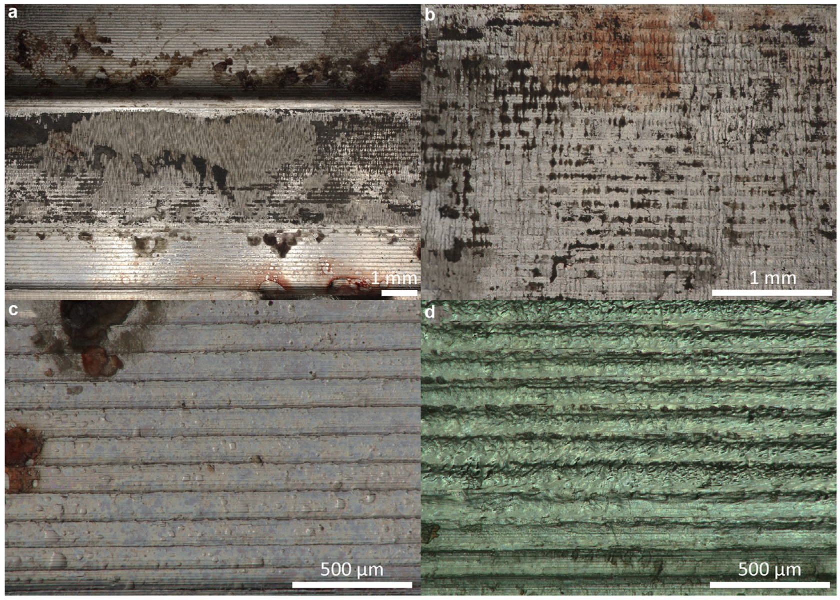

Figure 5. (a) A digital image shows heterogenous damage modes within the contact region including (b) oxide debris, column damage, and (d) MACC. Outside of the contact region, (c) areas of the CoCrMo appear blue and brown, indicating structural changes to the passive oxide film. CoCrMo, cobalt chrome alloy.

micrographs, areas of the original machined surface remain, evidenced by uniform, continuous stretches of CoCrMo. At the base of the coalesced pits in Figure 11c, new pits nucleate.

Black oxide debris (Fig. 12) remains one of the most easily recognizable forms of corrosion, visible during revision when surgeons separate modular metal components. Paired secondary (Fig. 11a) and BSE (Fig. 12b) images show a plate-like oxide film directly next to severe column damage. Energy dispersive x-ray spectrometry (EDS) maps qualitatively show titanium (Fig. 12C), oxygen (Fig. 12d), silicon (Fig. 12e), Cr (Fig. 12g), and molybdenum (Fig. 12h) in the corrosion debris. In the substrate alloy, maps identify mostly Co (Fig. 12f), Cr, and molybdenum. Region spectra ($n = 3$) acquired on both the oxide debris and the degraded CoCrMo quantify these findings (Fig. 12i). Note the increase in molybdenum in the corrosion debris (20.3%) compared to the substrate alloy (6.6%).

Discussion

The present case demonstrates clinical failure of an apparently well-seated DM liner implanted in vivo for only 10 months due to extensive corrosion at the CoCrMo-titanium alloy liner-cup interface and subsequent metal-related complications, evidenced by elevated serum metal ions, an effusion on advanced imaging, and a thickened capsule intraoperatively, which are findings consistent with the diagnosis of ALTR [4,33]. While the retrieval analysis, combined with an otherwise negative clinical workup, supported this diagnosis, the low ALVAL score did not. The patient underwent revision surgery with a head-liner exchange to remove the CoCrMo DM liner and place a cross-linked polyethylene liner and ceramic head, with resolution of symptoms. Given the patient's elevated serum metal ions preoperatively and subsequent findings of corrosion on explant analysis, her clinical failure was likely

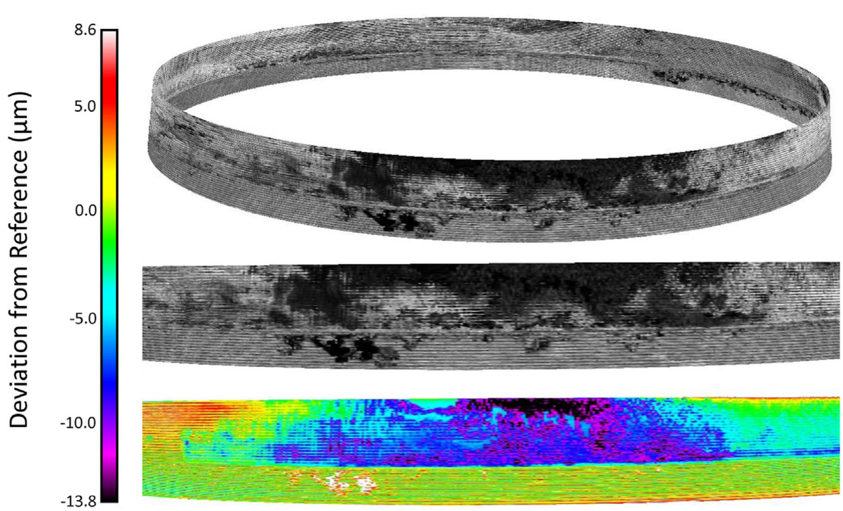

Figure 6. Using a coordinate measuring machine, we measured 0.76 ± 0.03 mm^3 of material loss from the CoCrMo DM liner. Regions with macroscopic column damage deviated the most from the reference, appearing black and purple in the associated heat map. CoCrMo, cobalt chrome alloy; DM, dual mobility.

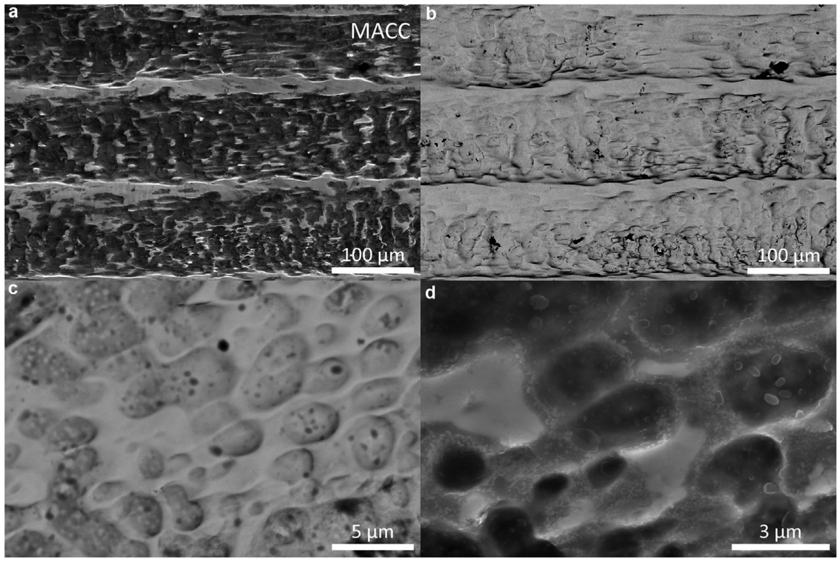

Figure 7. Scanning electron micrographs from the retrieved liner show MACC. (a) Machined lines plastically deformed. (b) In between the machine lines, chemically based corrosion processes generate oval-like features. (c) These appear elongated and interconnect. (d) Debris collected at the bottom of each oval.

secondary to corrosion, which has been previously demonstrated as a potential cause of revision THA with modular CoCrMo DM implants [4,34,35]. While this complication has often been attributed to liner malseating in prior literature, this case demonstrates that metal-related complications are possible for well-seated constructs. This case also demonstrates that the dome peg and antirotation tabs included in this modular DM liner design, which are features reported by the manufacturer to intentionally reduce the risk of malseating and corrosion, may still allow for MACC to occur [36].

DM implants have been previously shown to corrode in vivo at the cup-liner interface, with malseating being associated with this finding [26-28,37,38]. Terhune et al. analyzed 28 modular DM implants, classifying corrosion severity using the modified Goldberg Score and investigating its association with liner seating [27,39]. These implants had been in vivo for a mean of 14.6 months and were revised for concerns of instability, infection, loosening, or impingement. Analysis of these implants demonstrated grade 2 or greater corrosion in 85% of implants, with malseating being significantly associated with volumetric material loss [27]. Hemmerling et al. evaluated 60 retrieved liners from DM implants, demonstrating fretting in 88% and corrosion in 97% of implants. Additionally, tissue analysis conducted in 48 of these patients demonstrated histologic evidence of an inflammatory reaction in 6 patients [38]. Synthesizing the results of these studies, along with the reported rate of DM malseating in large studies ranging between 1.3% and 11.1%, and even well-seated liners, as was the case in the present report, concern over the risk of corrosion with the use of modular CoCrMo DM liners may be warranted [26,28,37]. A recent case report by Yang et al. reported aseptic loosening of a THA

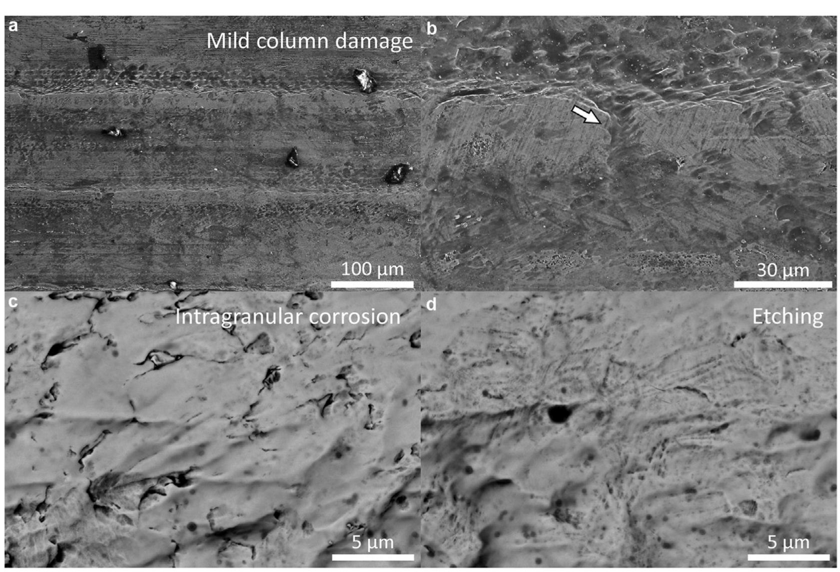

Figure 8. (a) Mild column damage can provide insights into how the chemically based corrosion damage mode initiates. (b) A column orthogonally intersects a plastically deformed machine line. Initial (c) column and (d) trough structures appear burnished. (c) While grain boundaries corrode within the columns, etching preferentially attacks the grains within the troughs.

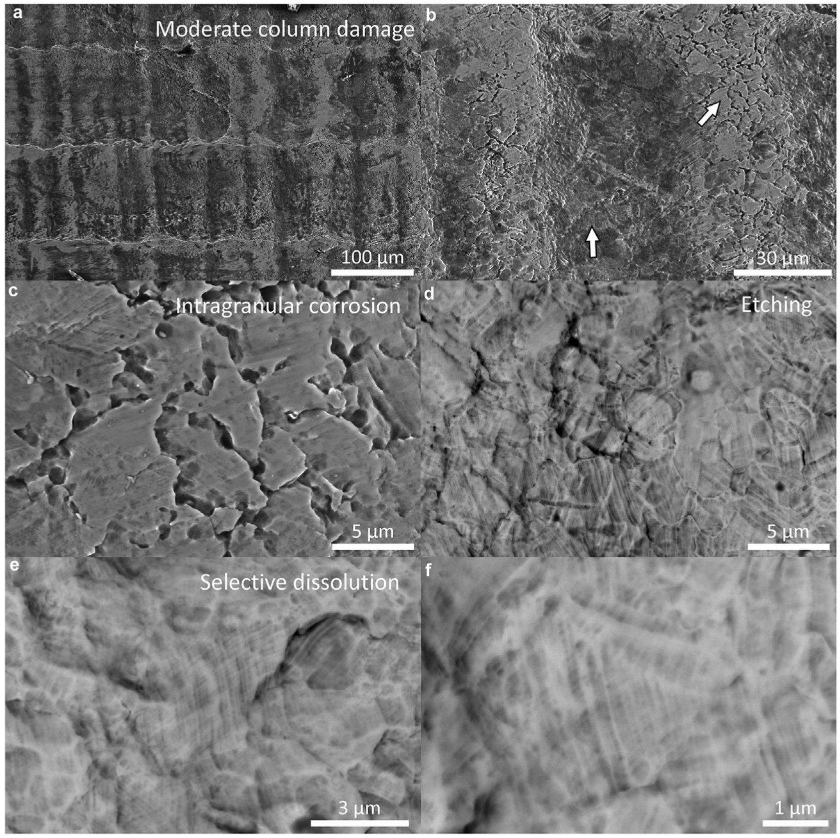

Figure 9. (a) Material loss within the troughs characterized moderate column damage on the retrieved CoCrMo liner. Note the plastically deformed machine lines, decreasing in thickness compared to the mild column damage in Figure 7b. Here, corrosion is clearly bimodal. (c) Intragranular corrosion completely dissolved the grain boundaries from the column surface, while (d) etching promoted material loss in the trough. (e-f) At higher magnifications, lattice structures become visible in etched grains, evidence of a selective dissolution attack. CoCrMo, cobalt chrome alloy.

with a modular DM component with macroscopic evidence of corrosion at the liner-cup junction, lending further credibility to the concept of corrosion in the well-seated DM implant [40].

Retrieval analysis of the CoCrMo liner revealed column damage as the primary degradation process, promoted by MACC [41]. Indeed, once cleaned, the columns and troughs could be visually

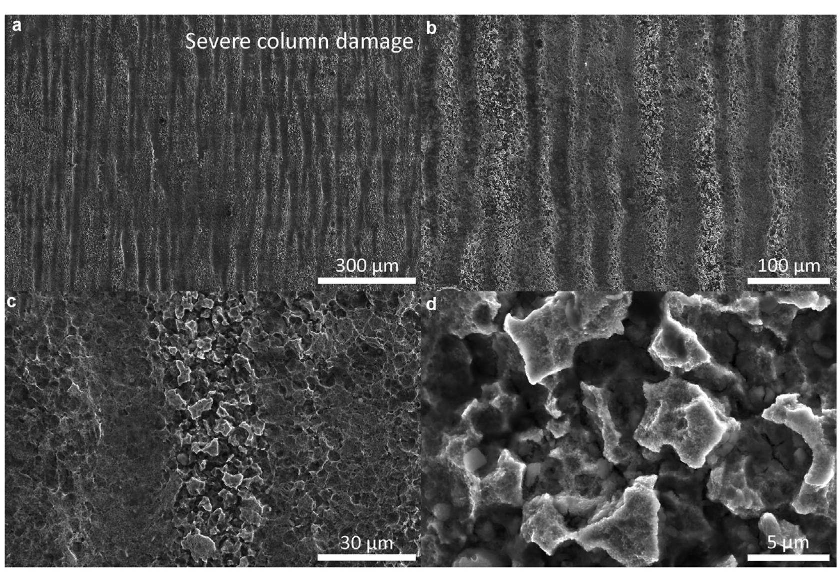

Figure 10. On regions of the liner with severe column damage, we documented (a) complete degradation of the machine lines and (b) continuous columns and troughs. (c) Corrosion processes remained bimodal. In the troughs, pitting dominated. (d) A more general corrosion attack degraded the remaining wrought CoCrMo grains on the columns, with voids interspersed throughout. CoCrMo, cobalt chrome alloy.

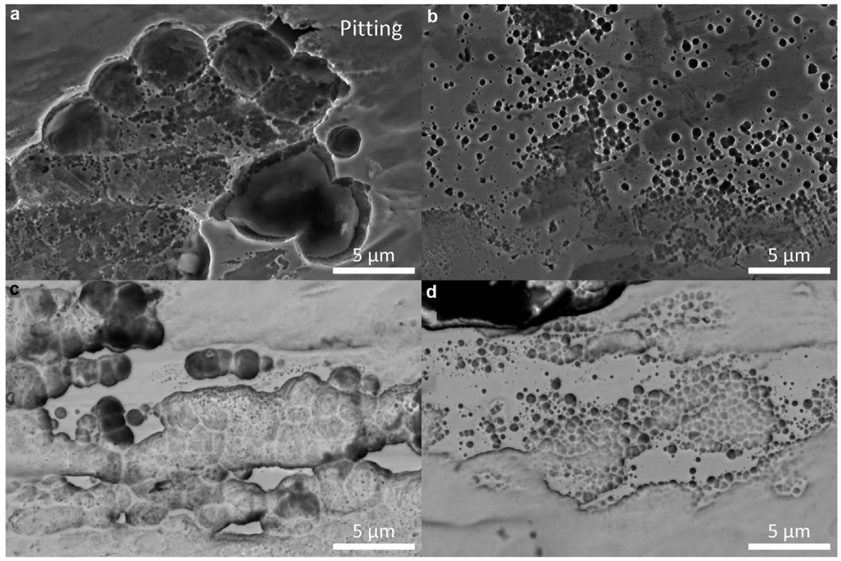

Figure 11. Micrographs document pits on the retrieved liner. Note the contrasting diameters in (a) and (b). (c-d) Pits grew and coalesced, interconnecting.

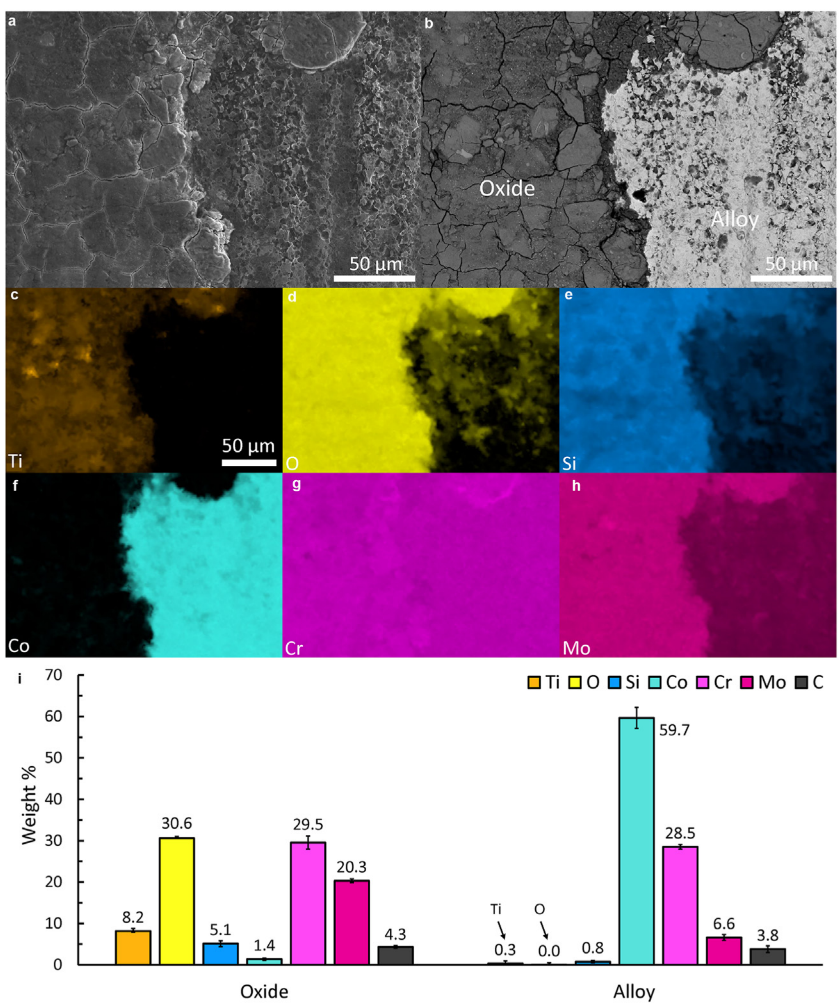

Figure 12. (a) Secondary and (b) BSE micrographs show oxide debris adjacent to severe column damage. Energy dispersive x-ray spectrometry (EDS) maps reveal (c) titanium, (d) oxygen, (e) silicon, (f) cobalt, (g) chromium, and (h) molybdenum. (i) Region spectra (n = 3) acquired on both the oxide debris and the substrate alloy quantifies the chemical differences. Note: To improve legibility, small boxes cover autogenerated text in the bottom left corner of each EDS map and should not be interpreted as the presence of an element.

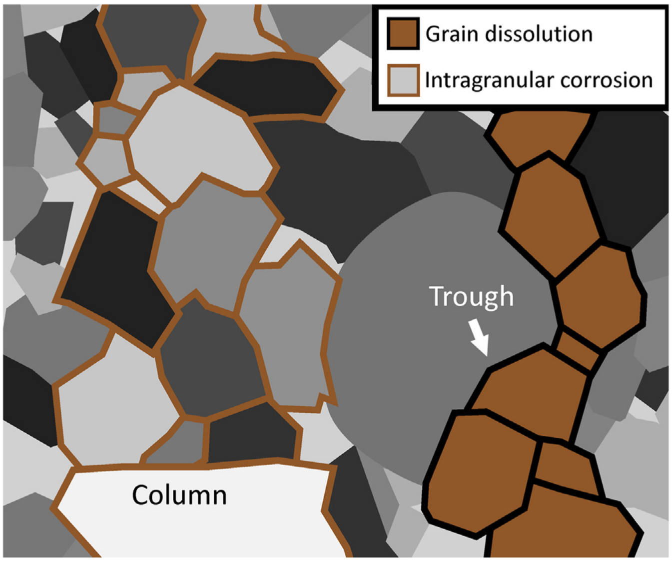

Figure 13. An illustration of the hypothesized bimodal corrosion mechanism shows intragranular corrosion processes preferentially corroding the columns. Within the troughs, etching dissolves the grains. Damage modes are overlayed on a wrought CoCrMo microstructure. This bimodal mechanism aligns well with existing hypotheses in the literature [32]. CoCrMo, cobalt chrome alloy.

identified without microscopy, like the accumulated and adjacent corrosion debris. Previous studies establish that column damage occurs on wrought, banded CoCrMo microstructures, typically observed in corroded femoral head tapers [41-44]. On these banded microstructures, scanning electron microscopy combined with EDS reveals chemical heterogeneity with molybdenum depleted regions [32,44]. Herein, we show how these regions and microstructural differences may influence column damage progression (Figs. 12 and 13).

On the columns, damage initiates as intergranular corrosion before transitioning to a more general corrosion attack. Within troughs, preferential dissolution of the grains rather than the grain boundaries appears to be the driving corrosion process. This too progresses, with micrographs revealing a pitting-like attack that is evidenced by voids in the severely corroded trough. Thus, our retrieval work provides unique insights into the column damage mechanism, suggesting bimodal, microstructurally driven processes. These findings align well with existing hypotheses, where a second corrosion mechanism is thought to occur beyond the molybdenum depleted regions [32]. However, the retrospective nature of retrieval analysis prevents us from determining whether the bimodal corrosion occurred concurrently, or if corrosion began preferentially.

Based on the findings of this case report and retrieval analysis, we believe that metal-related complications should be considered in the differential diagnosis of a patient with a THA presenting with hip pain and/or instability, particularly in constructs that contain a modular metal–metal interface and even in cases where the components appear well-seated radiographically. An infectious workup should certainly be undertaken in these patients to rule out any competing diagnoses, but given the relative ease of obtaining metal ion serum levels, this should be an added preoperative consideration in patients experiencing clinical symptoms with a modular metal-on-metal interface, especially given the potential local tissue destruction that can be associated with these reactions [4,34,45,46].

This case report experienced several potential limitations. First, as is inherent to case reports, the information presented represents our experience with just 1 patient and should be interpreted with appropriate caution. While it's unlikely that all implants of this design experience a similar outcome (eg, clinical failure associated with metal release), we do believe attention should be given to consider the diagnosis of metal-related complications in patients with this or similar modular DM designs. Given the clinical complications experienced by patients with metal-release associated failures in total joint arthroplasty, we believe a metal-related workup should at least be considered in symptomatic patients with modular CoCrMo liners regardless of their design or appearance of proper seating on radiographs. Second, while this patient certainly had corrosion and metal release from her implant, it is possible that her clinical symptoms were caused by factors other than a reaction to metal debris, such as capsular thickening or surgical healing. The patient indeed had a low ALVAL score of 4 and demonstrated only capsular thickening and a small effusion that was seen on magnetic resonance imaging. While these may not represent significant changes to fully support the diagnosis of ALVAL (and ALTR), we also note that this implant had only been implanted for 10 months. It is possible that such a short time of implantation could account for the lack of more advanced changes. Ultimately, while other etiologies of the patient's pain may exist, we believe that the elevated Co and Cr ions that have returned to normal, the findings of extensive corrosion at the DM interface, and the resolution of the patients' pain and symptoms with a revision that consisted of exchanging the head and liner support the likelihood that a reaction to the metal debris was the most likely contributing factor. Finally, the retrieval analysis presented is only representative of 1 patient's implant. A larger sample of retrieved liners with banded CoCrMo microstructures would provide additional insights into the prevalence of column damage at DM interfaces with this and other implant designs.

Summary

Following the rigorous rule out of other clinical failure modes, complications associated with metal release should be considered for DM THA constructs when there is a modular metal–metal interface present, even in the setting of a radiographically well-seated implant. Measuring serum metal concentrations and appropriate revision surgery should be considered if corrosion and subsequent metal release is present.

Conflicts of interest

Michael A. Kurtz is a paid consultant for Gyroid LLC and received other financial or material support from Gyroid LLC. Christopher Pelt received royalties from Total Joint Orthopaedics and Smith & Nephew; received speakers bureau/paid presentations for Total Joint Orthopaedics and 3M; is a paid consultant for 3M and Total Joint Orthopaedics; holds stock or stock options in Joint Development, LLC; received research support from Zimmer Biomet and Peptilogics as a Principal Investigator; and is a board member of AAHKS and AAOS. Steven M. Kurtz received speakers bureau/paid presentations for Gyroid LLC; is a paid consultant for Gyroid LLC; received research support from Celanese, CeramTec, Invibio, Mitsubishi Chemical Advanced Materials, 3Spine, Seqens, Enovis, Orthoplastics, SINTX Technologies, and Stryker as a Principal Investigator; received other financial or material support from Gyroid LLC; and received royalties, financial or material support from Elsevier. All other authors declare no potential conflicts of interest.

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Informed patient consent

The author(s) confirm that written informed consent has been obtained from the involved patient(s) or if appropriate from the parent, guardian, power of attorney of the involved patient(s); and, they have given approval for this information to be published in this case report (series).

CRediT authorship contribution statement

Allan K. Metz: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Michael A. Kurtz:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Cameron R. Egan:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Steven M. Kurtz:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Christopher E. Pelt:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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