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Case report

Severe Corrosion of Modular Dual Mobility Acetabular Components Identified During Revision Total Hip Arthroplasty

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ABSTRACT

There has been a significant increase in the use of modular dual mobility (MDM) acetabular cups for primary and revision total hip arthroplasty (THA) secondary to decreased dislocation rate and increased impingement-free range of motion. Mating of dissimilar metals in THA can result in mechanically assisted crevice corrosion, with increased serum metal ion levels and potentially adverse local tissue reaction that can lead to revision surgery. In this case report, we present a patient who had THA using MDM components, and his follow-up laboratory testing showed asymptomatic elevated serum cobalt level. The patient subsequently developed an intraprosthetic dislocation that required revision surgery. At the time of revision, significant corrosion was noted on the backside of the modular acetabular liner and the inner surface of the titanium shell. Serum cobalt levels returned to normal after revision surgery. This case suggests that mechanically assisted crevice corrosion at the modular surface of MDM components does occur. In addition, we believe surgeons should judiciously use MDM technology only for patients at significantly increased risk of dislocation after THA.

Introduction

The use of modular dual mobility (MDM) components during primary and revision total hip arthroplasty (THA) has grown substantially over the past 5 years [1,2]. In fact, for primary THA, dual mobility utilization increased from 6.7% in 2012 to 12% in 2018, and for revision THA, the utilization rate increased from 19.5% to 30.6% in 2012 and 2018, respectively [3]. Increased utilization is likely driven by enhanced articulation stability provided by combining the low-friction principle of Charnley [4], with the increased femoral head-to-neck ratio concept of McKee-Farrar [5]. Dual mobility articulations allow for increased head sizes [6]. A large femoral head size coupled with motion at 2 articulating surfaces permits for increased range of motion before neck-socket impingement and also increases the articular jump distance leading to a low incidence of dislocation [7-10]. Furthermore, the advent of modularity has facilitated the ease of implantation. The initial dual mobility construct used a monoblock cobalt-chromium acetabular component that did not allow for supplemental screw fixation or attachment of a stable insertion handle, leading to challenges with implant placement and initial stability [8]. Contemporary MDM components consist of a male cup liner of cobalt chromium, performing effectively like a trunnion that interfaces with a titanium female taper on the acetabular shell [10,11].

Owing to this combination of dissimilar modular metals, concerns related to fretting corrosion leading to elevated blood metal ion levels and adverse local tissue reaction (ALTR) are justified. Two recent publications have described significantly elevated blood metal ion levels in approximately 10% of patients with MDM components [12,13]. In addition, several cases of ALTR requiring revisions were found in these patient cohorts. The most common mechanism proposed for fretting corrosion between dissimilar metals is mechanically assisted crevice corrosion (MACC) [14,15]. Conclusions from previous reports indicate that revision surgery may be required for MACC-induced ALTR in patients with a serum cobalt level of 1.6 mcg/L and above [12,16]. When MACC occurred between modular junctions, serum cobalt levels are found to be elevated out of proportion to chromium values. Cobalt ions are associated with activation of human toll-like receptor 4, which is a component of the innate immune response to bacterial lipopolysaccharide in sepsis. Activation of toll-like receptor 4 by lipopolysaccharide increases the expression of chemokines IL-8 and

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Figure 1. Anteroposterior radiograph of the pelvis at 6 weeks postoperatively, showing well-aligned stem and properly positioned cup.

CXCL10, which recruit leukocytes and activate T-cells leading to the development of various adverse reactions, including inflammatory pseudotumor, soft tissue necrosis, osteolysis, and lymphocytic infiltration known as aseptic lymphocyte-dominated vasculitis-associated lesion [17,18]. For patients with significantly elevated serum metal ion levels, repeat laboratory analysis of the serum metal ion level and inflammatory markers (erythrocyte sedimentation rate and C-reactive protein) is recommended at 6-month intervals [12]. A magnetic resonance imaging study with a metal artifact reduction sequence protocol is recommended for any patient with a serum cobalt value ≥4.5 mcg/L [19,20].

In this case report, we present the findings of severe corrosion of MDM components which was recognized during revision THA performed for intraprosthetic dislocation (IPD).

Case history

A 55-year-old male presented to the hospital emergency room in September 2019 complaining of acute onset of severe left hip pain. His medical history revealed that in January 2011, he underwent an uncomplicated left THA for primary hip osteoarthritis performed through an anterolateral approach. MDM components were inserted and included 58-mm noncemented Tritanium shell (Stryker Orthopedics, Mahwah, NJ), 46-mm MDM liner, 28-mm standard cobalt-chromium ball, and size 5 lateral offset Accolade II stem (with 127° neck shaft angle) (Stryker Orthopedics, Mahwah, NJ). The polyethylene (PE) liner and metal head were assembled per manufacturer's instructions.

The patient's immediate postoperative course was unremarkable. At his sixth week postoperative appointment, the patient reported pain relief and restoration of function, and his radiographs showed well-aligned component (Fig. 1). He was seen at 6-month follow-up and was doing well with no remarkable findings.

During his routine follow-up approximately 2 and a half years after his index arthroplasty, the patient reported no complaints of pain and good function. However, owing to the rising concerns in the literature regarding elevated serum ion levels associated with MACC at the modular junctions, serum cobalt and chromium values were measured. Interestingly, the serum level of cobalt ions was found elevated at 2.0 mcg/L (reference value: 0.1-0.4 mcg/L), and serum chromium level was normal at 0.4 mcg/L (reference value: ≤1.4 mcg/L). As the patient was asymptomatic at that time, serum ion reevaluation was scheduled approximately 6 months later. At his reevaluation, despite continuing to be asymptomatic, the serum cobalt level had risen to 3.1 mcg/L, while his chromium remained at 0.4 mcg/L. At this point, metal artifact reduction sequence protocol magnetic resonance imaging was obtained and interpreted as shown in early findings of ALTR. One year later, during his reevaluation, the patient was still doing well, but serum cobalt level was still high at 3.2 mcg/L and serum chromium was 0.3 mcg/L. Once more, because the patient was asymptomatic, follow-up check after 1 year was recommended. At the next evaluation (approximately 5 years since the primary surgery), the patient was still doing well. Serum cobalt had decreased to 1.6 mcg/L, and serum chromium level remained within the reference range. Radiographs showed well-positioned THA components with no radiological signs of osteolysis or loosening (Fig. 2). Accordingly, reassessment within 2 years was advised. As the patient was doing well, he did not return for his reevaluation and continued to function normally.

Approximately 8 years after the index surgery and 3 years from his last clinic visit, the patient had an acute onset of hip pain 2 days before presentation to the emergency department. Evaluation in the emergency department revealed that he was having severe pain in the groin area and was unable to ambulate. He reported that

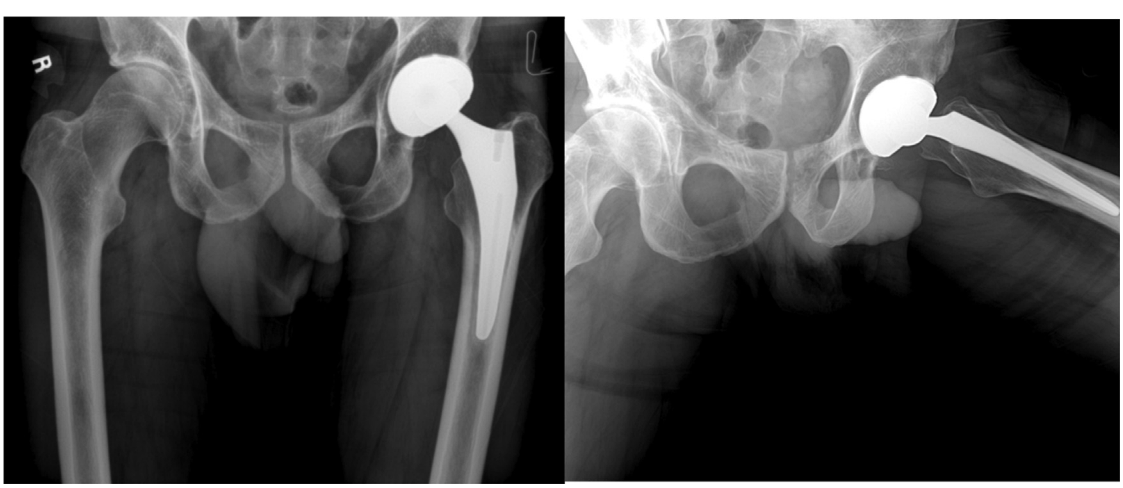

Figure 2. Anteroposterior and lateral radiographs at 5-year postoperative follow-up. This was the last available radiograph before the dislocation event. Component appeared correctly positioned and well-fixed.

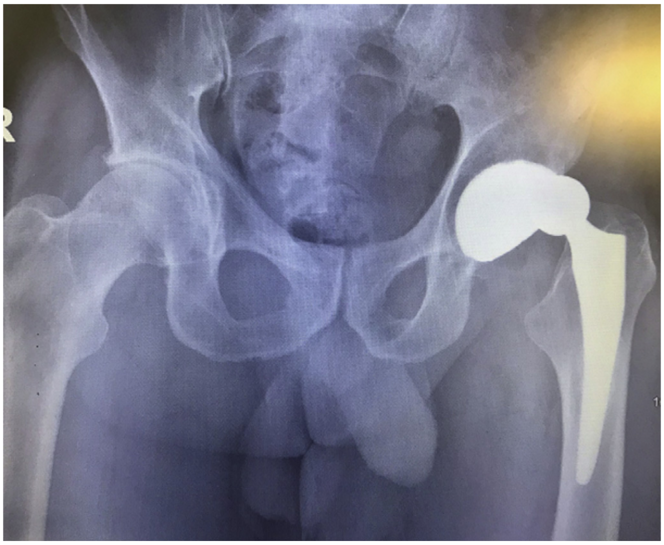

Figure 3. Anteroposterior radiograph of the pelvis at the time of presentation to the emergency room revealed an eccentric location of the prosthetic head.

the pain began upon turning while setting on the beach and was preceded by an audible “pop” emanating from the left hip region. Hip radiographs (Fig. 3) and a CT scan were obtained and revealed an IPD of the left hip MDM construct. Closed reduction was attempted but was unsuccessful. The patient had revision surgery on the following day.

Intraoperatively, upon exposure through the previous anterolateral incision, an IPD was noted. No evidence of tissue necrosis or ALTR was found. The femoral head was disassociated from the PE liner, while the cobalt-chromium liner was completely inserted into the titanium acetabular shell and was well-fixed. Upon retrieving the MDM PE liner, an area of severe localized focal wear was identified at the posterosuperior aspect (Fig. 4). Then, the 28-mm cobalt-chromium femoral head was removed, and careful

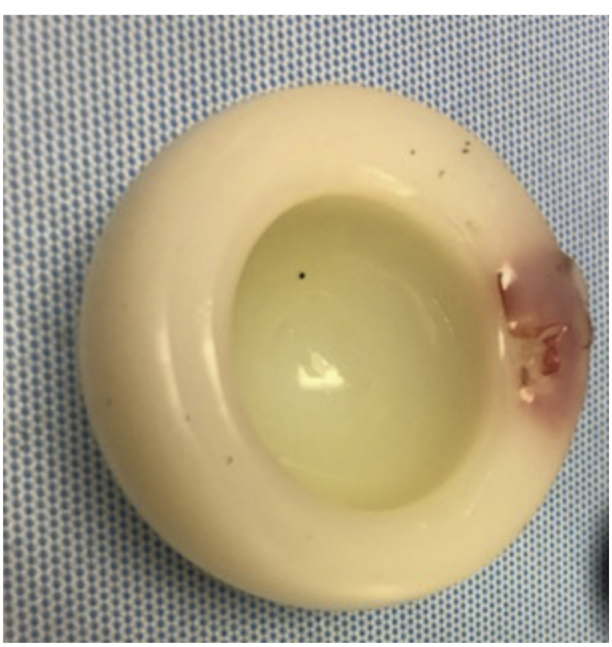

Figure 4. Modular dual mobility polyethylene liner with focal damage at the posterosuperior aspect.

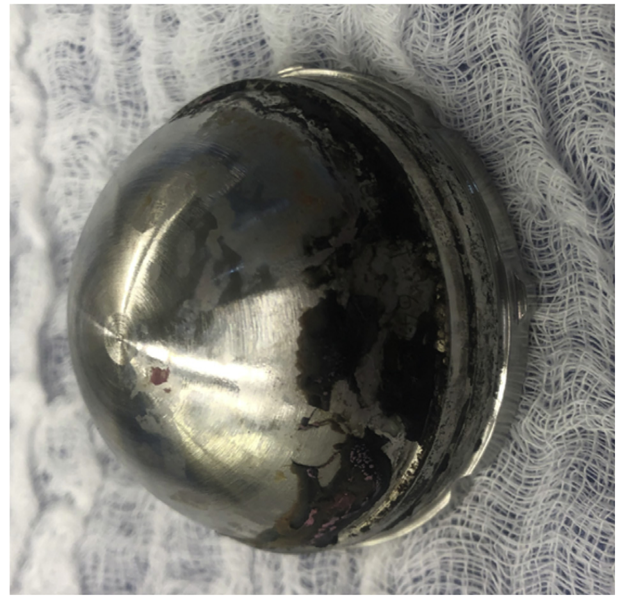

Figure 5. Backside wear of the modular cobalt-chromium insert. Note the black, chromium-rich surface consistent with mechanically assisted crevice corrosion (MACC).

inspection revealed no corrosion with only minimal damage to the trunnion. The modular cobalt-chromium acetabular liner was removed and inspected. The titanium acetabular shell was well-fixed. On inspection of the MDM components, evidence of black debris, pitting, and etching indicating severe corrosion debris was found on the backside of the cobalt-chromium liner (Fig. 5) and on the interfacing inner surface of the titanium shell (Fig. 6), with a score range of 3-4 according to the corrosion classification method (Table 1) [21]. Both the femoral stem and the acetabular titanium shell components were well-fixed and well-positioned.

The corrosion debris on the titanium cup was thoroughly debrided, and a Stryker Orthopedics 36-mm highly cross-linked PE liner was inserted into the shell. A titanium sleeve was placed over the trunnion, and a +7.5, 36-mm ceramic head (Stryker Orthopedics) was inserted. Final reduction was performed. In the postoperative period, the patient recovered well without any episodes of instability. Capsular tissue was collected and sent for pathologic

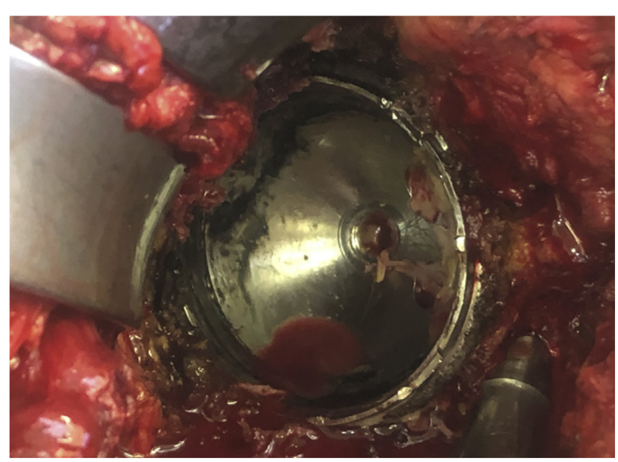

Figure 6. Titanium acetabular shell a time of revision surgery. Note the chromium-rich black surface consistent with mechanically assisted crevice corrosion (MACC).

Table 1
Criteria for corrosion and fretting score [21].

Severity of corrosion and fretting	Score	Criteria
None	1	No visible corrosion observed No visible signs of fretting observed
Mild	2	<30% of taper surface discolored or dull Single bands or bands of fretting scars involving 3 or fewer machine lines on taper surface
Moderate	3	>30% of taper surface discolored or dull, or <10% of taper surface containing black debris, pits, or etch marks Several bands of fretting scars or single band involving more than 3 machine lines
Severe	4	>10% of taper surface containing black debris, pits, or etch marks Several bands of fretting scars involving several adjacent machine lines, or flattened areas with nearby fretting scars

examination, which revealed an elevated tissue chromium level of 8.3 mcg/L (reference value: <0.15 mcg/L).

In the postoperative period, the patient recovered well without any episodes of instability. After 6 weeks, the patient reported pain relief and improved function, and the obtained postoperative radiographs showed well-aligned components. The patient has been regularly followed up in the clinic. At the 1-year postrevision visit, the patient showed satisfactory restoration of functionality including regular daily activities with no complaint of pain at the hip joint. Physical examination of the hip joint showed acceptable range of motion, joint stability, and adequate muscle strength bilaterally. Radiographs were obtained and showed satisfactory position and acceptable alignment of all THA components (Fig. 7). The patient gave his consent to publish this case report, including the clinical data and the radiological images.

Discussion

This case report describes 2 potential problems associated with the use of MDM component in THA. This patient had an intraprosthetic dislocation of an MDM component and severe corrosion of the interface between the modular cobalt-chromium liner and the acetabular titanium shell. Despite the co-occurrence of both adverse events, the correlation between them cannot be determined.

MACC at modular metal junctions during THA has been demonstrated to be a serious concern, sometimes leading to significant complications and the need for revision surgery [16,20,22]. Micromotion between 2 dissimilar metals is necessary for MACC to occur. This motion leads to the hallmark findings of chromium-rich black surface deposits and serum cobalt levels significantly higher than chromium levels [23,24]. A recent retrieval analysis of modular cobalt-chromium acetabular inserts revealed evidence of corrosion at the titanium shell-cobalt-chromium modular insert interface [23,25]. This is consistent with our case report, where obvious corrosion was identified on the backside of the acetabular insert and inner surface of the titanium shell. In addition, the elevated serum cobalt levels, independent of chromium levels, is consistent with MACC.

Mechanisms for the induced micromotion leading to MACC are not fully understood, but recent evidence suggests malseating of the cobalt-chromium insert may be a contributing factor. Wright et al. created a crevice environment conducive to erosion using an electrochemical chamber and MDM liners [26]. Two liners were well-seated, and 2 liners were canted at 6 degrees. After cyclic loading at physiologic levels, the authors found that malseating the insert at around 6 degrees compared with the well-seated liner leads to increased fretting corrosion at physiologic loads [26]. This is important to note, as the same group identified nearly 6% of MDM constructs implanted over a 2-year period at their institution were malseated on postoperative radiographs [27]. While our patient was not found to have a malseated insert, either intraoperatively or when reviewing previous radiographs, surgeons using MDM constructs must be cognizant of the potential to malseat the insert and its resultant consequences.

Another potential mechanism for MACC, which may have occurred in our patient, involves impingement. The contemporary

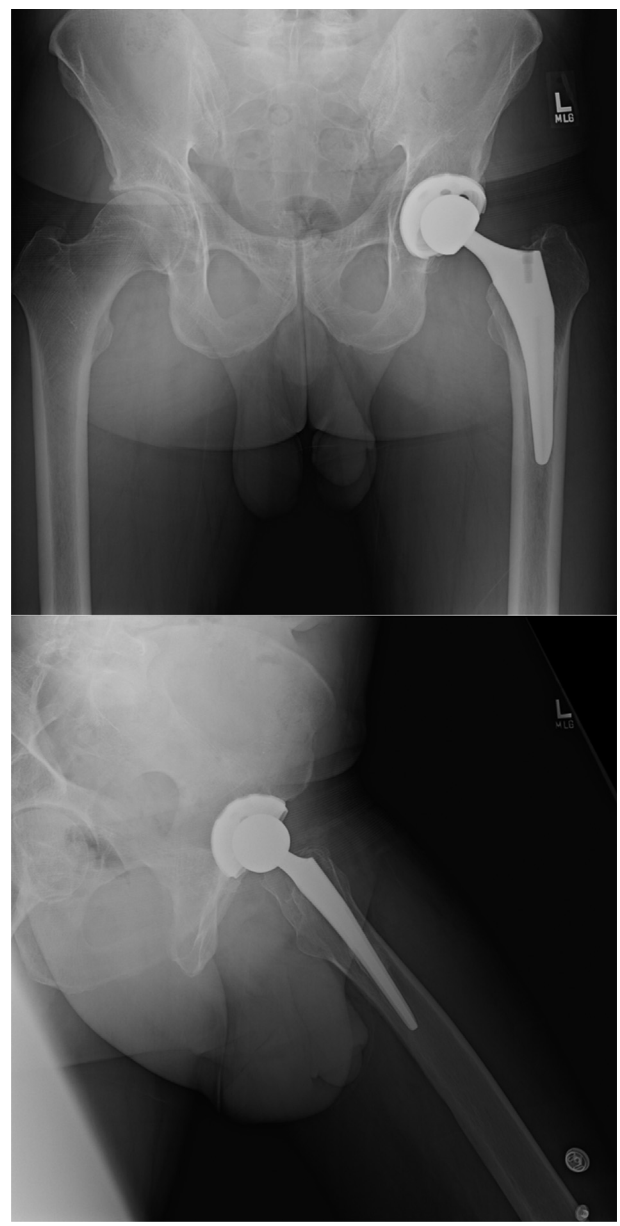

Figure 7. Anteroposterior and lateral radiographs of postrevision surgery of the hip.

Figure 8. Stryker Orthopedics (Mahwah, NJ) modular dual mobility (MDM) hip system. Note the elevated acetabular insert (red arrow) that may be a source of femoral neck impingement, leading to micromotion at the modular surface and ultimately, mechanically assisted crevice corrosion (MACC).

Stryker Orthopedics MDM cobalt-chromium liner has a lip extending above the titanium acetabular shell (Fig. 8). Impingement of the femoral neck on this elevated lip is certainly possible and likely, particularly in younger active patients. This impingement could easily create the interface micromotion needed to facilitate MACC for this modular device. To our knowledge, there is no current biomechanical evidence to support this theory, thus further research into the subject is warranted.

On the other hand, IPD is a unique failure mechanism of dual mobility THA induced by the loss of the PE retentive rim which leads to the inner prosthetic femoral head to escape from the outer PE bearing [28]. IPD may occur any time after the index procedure; however, it is predominantly a late complication, reported at an average of 9 years after the index THA [29]. Revision surgery is needed to correct IPD [28,30]. In our case, one possible explanation of IPD is posterosuperior PE wear which occurred in the setting of normal modular articulation and led to gradual loss of the inner PE capture mechanism [31,32]. Another theory for disengagement is failure of the dual mobility mechanism secondary to blocking of the larger PE articulation motion caused by associated arthrofibrosis or heterotrophic calcification [29]. Association between soft tissue thickening and high levels of local metal debris has been mentioned in many reports [33,34]. When the PE liner stops working as a dual mobility component, motion of the THA will only occur between the femoral head and the fixed PE liner. This results in a decrease in the effective head size from 46 mm to 28 mm leading to loss of the large diameter head concept and a significant drop in impingent free range of motion. This decrease in the range of motion leads to modular neck impingement against the PE during daily range of motion activities. Wear leading to the extensive focal damage, with eventual failure of the capture mechanism of the larger articular PE liner, may occur.

Summary

In summary, this case report proves that MACC of MDM devices does occur. While the frequency of this problem is unknown, the authors strongly recommend (1) judicious use of MDM technology with restriction of use limited to only patients at very high risk of instability, (2) further basic science and biomechanical investigation into our proposed mechanism for MACC of MDM components, (3) redesign of these components to reduce the potential for liner-femoral neck impingement and liner-locking mechanism enhancement, and (4) routine evaluation of patients who have had THA using MDM components for elevated serum metal ions levels and ALTR.

Conflict of interests

P. F. Sharkey received royalties from Corentec Orthopaedics, Stelkast, and Zimmer-Biomet; is in the speakers' bureau or gave paid presentations for Convatec, Corentec Orthopaedics, and Zimmer-Biomet; is a paid consultant for Corentec Orthopaedics and Zimmer-Biomet; has stock or stock options in OBERD and Physician Recommended Nutriceutcals; is in medical/orthopaedic publications editorial/governing board of American Journal of Orthopedics, CORR, JOA, and Seminars in Arthroplasty.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2021.01.011.

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