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Case report

Metallosis and Corrosion Associated With Revision Total Knee Arthroplasties With Metaphyseal Sleeves

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A R T I C L E I N F O

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A B S T R A C T

Metallosis and corrosion have been associated with metal-on-metal and modular total hip arthroplasty but are rarely described in the setting of primary or revision total knee arthroplasty (TKA). In this series, we report on cases of metallosis due to mechanically assisted crevice corrosion at modular junctions of machined trunnion-bore tapers in a revision TKA system with metaphyseal sleeves. The unique design of metal modular junctions used in sleeve-based revision TKA, along with potential patient and surgical factors, may predispose these designs to fretting, corrosion, and adverse reaction to metal debris. We now consider metallosis and corrosion in the workup of painful or failed revision TKAs with sleeves. Future studies that investigate the incidence of this phenomenon may be warranted.

Introduction

Much attention has been paid to metallosis associated with metal-on-metal (MoM) and modular total hip arthroplasty (THA) [1-11]. In recent years, we have been introduced to the new "disease" of taper corrosion in THA [12]. Metallic implants may corrode in a biologic environment [13,14]. While less often discussed, corrosion-related issues may also occur in total knee arthroplasty (TKA) [15-17]. In revision TKA, deficient bone stock and fixation challenges commonly occur. To improve fixation and fill defects, the use of cones or sleeves to achieve metaphyseal porous ingrowth have become popular. Morgan-Jones et al. described zonal fixation in revision TKA and recommended zone 2 metaphyseal fixation with cones or sleeves due to the compromised quality of the epiphyseal bone seen in many revisions [18]. Fretting, corrosion, and taper material loss have been reported in some revision knee arthroplasty taper junctions [19,20]. Both cones and sleeves have been associated with favorable survivorship and clinical outcomes [21-26]. However, sleeve-based revision TKA systems have been shown to have unique failure mechanisms, with prior reports focusing on the failures of the modular offset adapter and locking bolt of the femoral component, leading to metallosis [27-34]. However, to our knowledge, the issue of taper corrosion at the implant-sleeve interface of revision TKA has not yet been described in the literature. Mechanically assisted crevice corrosion (MACC) has been described as cobalt-chromium (CoCr) against titanium (Ti) in modular THA [35-39]. Given the similarities in reliance on CoCr-Ti modular junctions, extrapolating what we have learned from corrosion and metallosis-related issues in THA to the setting of primary and revision TKA may be warranted.

We have observed multiple instances of pain, implant failure, and bone loss following revision TKA with metaphyseal sleeves with associated elevated serum and synovial ion levels and bone loss concerning for metallosis, without the previously described failure of the modular offset coupler or locking bolts. In this case series, we describe 4 representative cases from a larger and growing series of revisions at our institution demonstrating 3 unique scenarios of MACC at modular junctions that led to knee revisions, scenarios that have not been described previously in the literature: 1) corrosion at the femoral component male trunnion-femoral sleeve female bore, above the modular offset coupler; 2) the tibial baseplate stem/trunnion-tibial sleeve female bore; and 3) the femoral male trunnion of hinged revision component mated to a reused well-fixed femoral sleeve. All patients provided written informed consent for the publication of their deidentified clinical data.

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Figure 1. Left revision total knee arthroplasty with Sigma TC3 knee system.

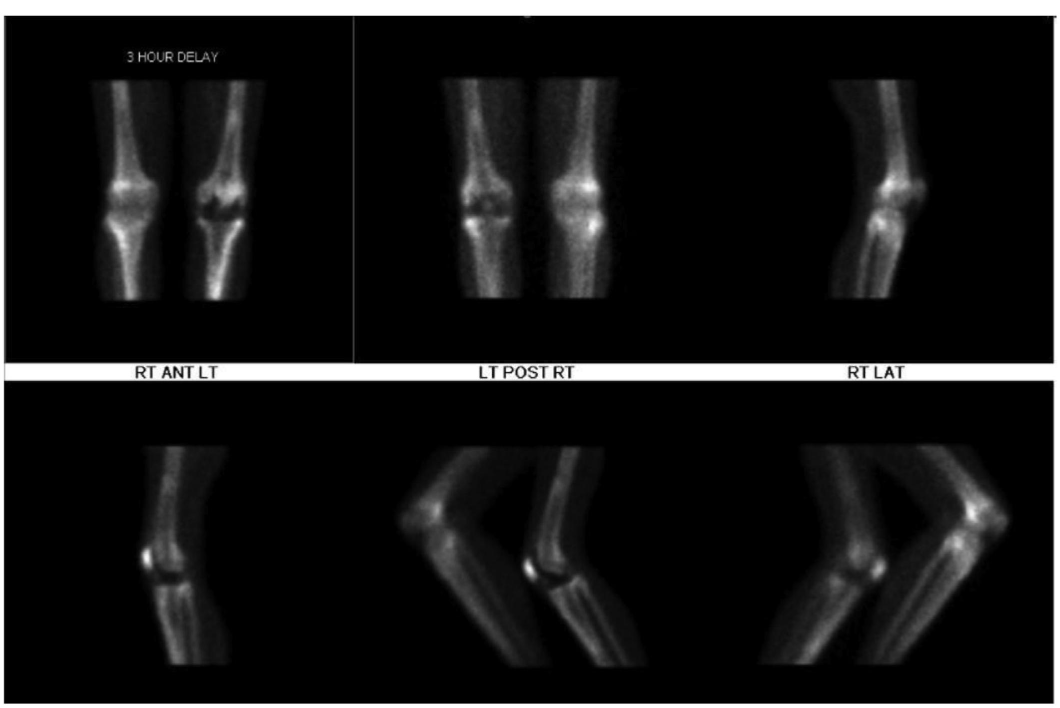

Figure 2. Triple phase bone scan demonstrating mild-to-moderate increased uptake at the lateral aspect of the femoral implant.

Figure 3. Each picture of the female taper demonstrates a view of each of the etches that corresponds to the flat geometry on the male taper.

Case histories

Case 1

An 87-year-old patient presented to our clinic as a referral for ongoing left knee pain following TKA. He underwent a primary left TKA in 2015 with unknown implants. He then underwent revision TKA several months later for tibial loosening with a Sigma TC3 knee system (DePuy, Warsaw, IN) (Fig. 1). Following his revision, he suffered from lateral-sided knee pain. Initial workup 4 years following his original revision TKA yielded a C-reactive protein (CRP) of 0.2 mg/dL and erythrocyte sedimentation rate (ESR) of 4 mm/h. Aspiration of his left knee resulted in 111 WBCs with 44% polymorphonuclear leukocytes (PMNs). Serum metal ions resulted in a Co level of 1.9 μg/L and Cr of <1 μg/L. Given the concern for possible metallosis, the patient was asked to return in 6 months for repeat evaluation. At repeat evaluation, CRP was 0.1 mg/dL, and ESR was 4 mm/h. Serum metal ions were not processed at that time. However, synovial ions were notable for a Co level of 30 μg/L and Cr level of 1.3 μg/L. A triple-phase bone scan was obtained and demonstrated increased mild-to-moderate uptake at the lateral aspect of the femoral implant (Fig. 2). The diagnosis of taper corrosion of the femoral side of his TKA was presumed, and he subsequently underwent a femoral revision. The femoral offset adapter and locking bolt were intact, without fracture or loosening. Intraoperatively, the female bore of the metaphyseal sleeve had geometric mechanical etches/scoring with associated corrosion debris (Fig. 3). The male taper of the femoral component demonstrated a ring of wear and mild corrosion debris (Fig. 4). His tibial component was interrogated and found to be well fixed. Given the negative bone scan and intraoperative assessment, despite not being able to ensure a lack of corrosion at that taper as well, the tibia was retained. We proceeded with a femoral revision of his TKA with a short-cemented stem into a 3D-printed metaphyseal cone (Fig. 5). Over 1 year postoperatively, the patient was doing well with significant improvement in pain.

Case 2

A 64-year-old patient was referred to our clinic with bilateral, right greater than left knee pain, swelling, and stiffness after prior bilateral revision TKAs. She originally underwent staged, bilateral TKAs in 2008. She then underwent a right TKA revision in 2011 and a left TKA revision in 2012, both for arthrofibrosis, with the Sigma TC3 knee system (DePuy, Warsaw, IN) with porous sleeves (Fig. 6). She did well initially with these revision TKAs, but 1 year later, she began to develop pain in the right knee and subsequently the left knee, and she noted a progressive loss of range of motion (ROM) in

Figure 4. Male taper ring of wear and mild corrosion debris. The implant had been cleaned and sterilized since the explantation surgery.

Figure 5. Postoperative films after femoral revision with a short, cemented stem and metaphyseal cone. Implants appear well-fixed without radiolucent lines.

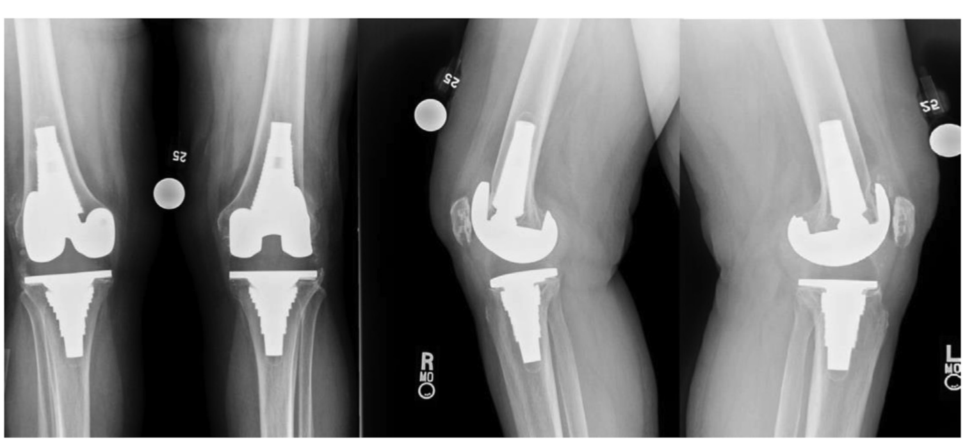

Figure 6. Bilateral revision total knee arthroplasties with Sigma TC3 knee systems.

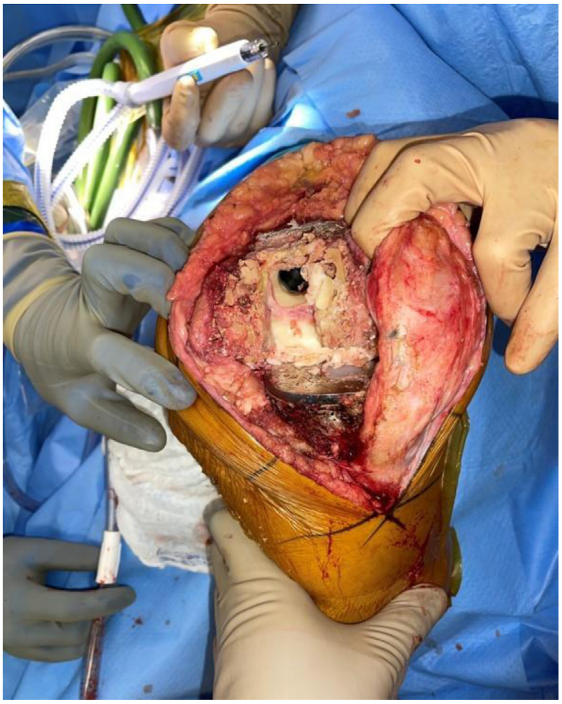

Figure 7. Abundant cement debris and fibrous tissue of a left revision total knee arthroplasty.

both knees. She was initially evaluated at an outside center, where she felt her right femur and left tibial components showed evidence of aseptic loosening and recommended bilateral revisions. When she presented to our clinic for a second opinion, her bilateral knee pain had worsened, she had an arc of motion of about 60 degrees in both knees, and the patient was amenable to revision surgery. CRP was 0.2 mg/dL, and ESR was 1 mm/h. Serum Co was <1 μg/L and Cr was 1.1 μg/L. Right knee aspirate was significant for 49 nucleated cells, 26% PMNs, a Co level of 6.9 μg/L, and Cr level of 3.1 μg/L. Left knee aspirate was significant for 20 nucleated cells, 4% PMNs, a Co level of 3.9 μg/L, and a Cr level of 2.2 μg/L. Given concern for bilateral TKA aseptic loosening, potential metallosis, and arthrofibrosis, our plan was for staged revision surgery of her TKAs,

Figure 8. Explanted left revision TKA implants with excision of tissue and corrosion are most notable at the tibial tray stem.

starting with her right side. Intraoperatively, the femoral condylar segment was debonded from the surface cement mantle, though the femoral sleeve was well-fixed. The femoral offset adapter and locking bolt were intact, without fracture or loosening. Corrosion was noted at the femoral trunnion to sleeve bore interface. There was abundant scar and fibrotic tissue throughout the knee. The tibial component was also removed. She was then revised to a Triathlon hinged TKA (Stryker, Kalamazoo, MI) utilizing metaphyseal cones, given substantial bone loss after removal of the well-fixed sleeves. Nine months later, the patient underwent revision of her left TKA with similar implants as the right side. Intraoperatively, there was similar abundant fibrotic tissue and evidence of corrosion debris, with significant corrosion at the tibial tray and sleeve interface (Figs. 7-9). Interestingly, in the left knee, we found the proximal tibial tray to be loose with a well-fixed tibial sleeve. The femoral offset adapter and locking bolt were intact, without fracture or loosening. The patient underwent placement of a short, cemented stem with impaction bone grafting and metaphyseal cone fixation with a hinged revision TKA (Fig. 10). At 15-month follow-up for her revision left TKA and over 2-year follow-up for her revision right TKA, she was doing well without any significant pain and had improved ROM of 0-115 degrees of flexion in both knees.

Case 3

A 65-year-old male with arthrogryposis initially underwent a primary right TKA in 2000 and a left TKA in 2001 at outside hospitals. His right knee was complicated by a methicillin-sensitive *Staphylococcus aureus* periprosthetic joint infection and underwent an irrigation, debridement, and polyethylene exchange along with IV antibiotics for 6 weeks and 6 months of oral antibiotics. In 2009, he underwent a revision right TKA for aseptic loosening of his implants and had no evidence of infection. In 2012, he presented to our clinic and had aseptic loosening of his bilateral TKAs. He subsequently underwent revision of his bilateral knees with Sigma TC3s (DePuy, Warsaw, IN) with porous sleeves (Fig. 11). Four years later, he again presented with instability of the right knee and had worn through his varus-valgus constrained post, likely due to the abnormal stresses and restricted motion from his arthrogryposis (Fig. 12). His implants/sleeves were well-fixed. He was subsequently revised to a S-ROM Noiles hinged TKA (DePuy, Warsaw, IN) by keeping his well-fixed tibial baseplate with the well-fixed mobile bearing technology (MBT) sleeve, which can accept the rotating hinge construct, as well as the well-fixed femoral sleeve (Fig. 12). Over time, the patient began suffering from recurrent effusions, and serial radiographs demonstrated progressive bone loss of the anterior cortex, despite his implants appearing well-fixed (Figs. 13 and 14). CRP was <0.1 mg/dL and ESR was 13 mm/h. Right knee aspiration revealed 124 nucleated cells and was culture-negative for organisms. Serum Co was 15.9 μg/L, and Cr was 8.0 μg/L. Right knee synovial Co was 580 μg/L, and Cr was 110 μg/L. The patient underwent revision of his right TKA. Intraoperatively, the grooves of the femoral trunnion were filled with abundant black corrosive debris, and the female bore of the femoral sleeve, which was well-fixed, was filled with corrosion debris (Figs. 15 and 16). There was a detectable acid-like smell noticed by the surgical team after disengaging the hinged femoral component from the sleeve. The anterior femoral cortex was eroded, exposing the anterior aspect of the otherwise well-fixed porous femoral sleeve. The well-fixed tibia was left in place, though we did not attempt to evaluate for tibial-sided corrosion. The femoral hinged component, femoral sleeve, and stem were removed, and the patient was revised to a segmental distal femur replacement with a fully porous stem, given the bone loss associated with removal of the well-fixed sleeve and stem

Figure 9. Tibial tray stem with abundant corrosion with associated magnified picture of corroded tibial stem.

(DePuy, Warsaw, IN) (Fig. 17). The patient is doing well after his recent surgery and 5-month postoperative visit.

Case 4

A 66-year-old male who initially underwent a right TKA at an outside hospital 8 years prior. He suffered from persistent pain and underwent a revision to a Sigma PFC TC3 Revision TKA (DePuy, Warsaw, IN). He presented to our clinic 4 years later with recurrent pain in his R TKA and a large soft tissue mass at the medial aspect of his knee (Fig. 18). A punch biopsy was performed at an outside facility, which revealed benign fibrous material, and he continued to drain from this site for 2 weeks. His CRP was 0.5 mg/dL and ESR was 10 mm/h. Right knee aspiration demonstrated 2,405 nucleated cells, 46% neutrophils, and was culture-negative. Serum Co was <1.0 μg/L, and Cr was 1.7 μg/L. Synovial Co was 1.7 μg/L, and Cr was

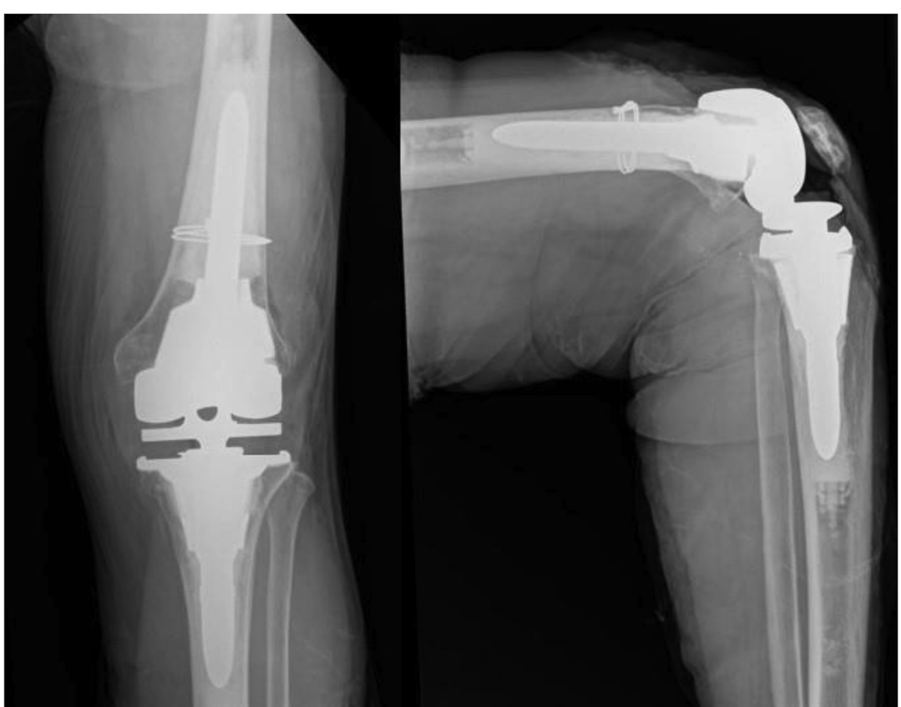

Figure 10. Postoperative films of the left total knee revision with short, cemented stems with impaction bone grafting and metaphyseal cone fixation with a hinged implant. Implants appear well-fixed without radiolucent lines.

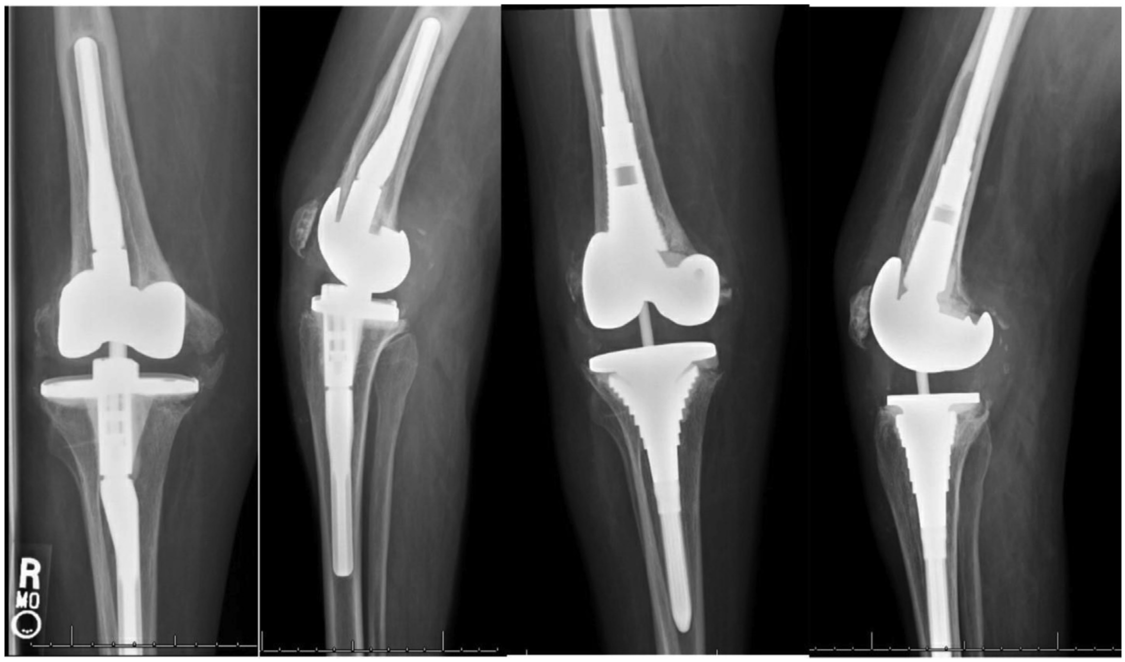

Figure 11. Preoperative and postoperative (1 year) images after revision to DePuy Sigma TC3 revision TKA with femoral and tibial metaphyseal sleeves. Revision was performed for aseptic loosening of a prior revision right TKA, as shown.

not detected. Radiographs and computed tomography scan of the right knee demonstrated medial tibial plateau erosion with an associated low-density mass vs fluid collection (Figs. 19-21). Given his history of draining sinus over his medial knee mass, which was believed to communicate to the hardware via the tibial erosion, the decision was made to perform a 2-stage revision TKA. At his stage one revision TKA, the knee did not appear infected, and all cultures were ultimately negative. The mass was decompressed, and an articulating antibiotic spacer was placed. Corrosion debris was seen at the end of the tibial female bore, near the site of the tibial bone erosion and adjacent mass that was consistent with a pseudotumor-like appearance (Figs. 22 and 23). The femoral

Figure 12. Preoperative and postoperative radiographs of the next revision TKA that was performed due to recurrent varus-valgus instability related to presumed wear of the constrained polyethylene post due to patient's arthrogryposis. The well-fixed MBT tibial baseplate, tibial sleeve, stem, and well-fixed femoral sleeve and stem were all retained. The constrained distal femoral component (Sigma TC3 femur) was removed and exchanged to an S-ROM Noiles Hinged Femoral Component. The femoral component was distally cemented, and the cleaned and dried female taper of the well-fixed femoral sleeve was reused, mating it with the new male taper of the hinged femoral component.

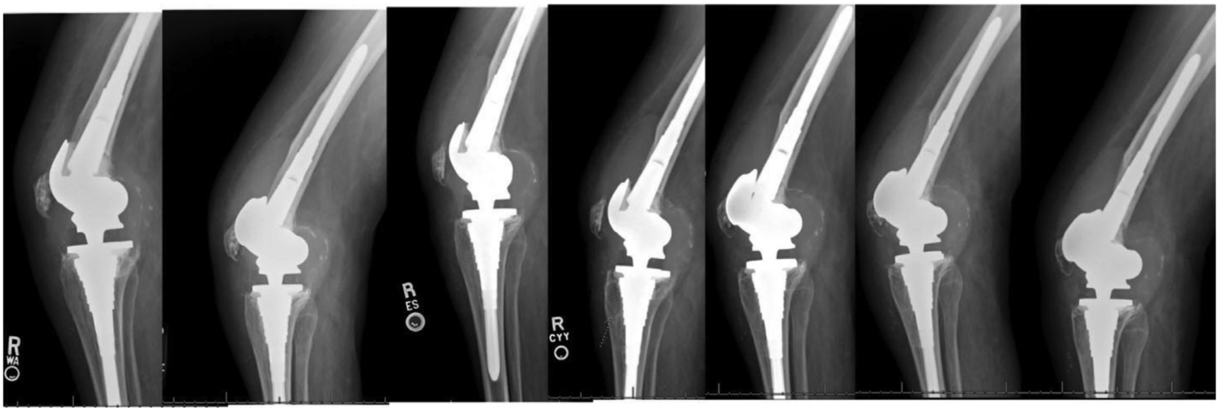

Figure 13. Serial lateral knee radiographs at 6 weeks, 1 year, 2 years, 3 years, 4 years, 5 years, and 6 years follow-up demonstrating a large effusion in the suprapatellar pouch along with adjacent progressive bone loss of the anterior cortex of the distal femur and an anterior tibial cyst, which became noticeable at year 2.

Figure 14. Serial anteroposterior radiographs at 6 weeks, 1 year, 2 years, 3 years, 4 years, 5 years, and 6 years demonstrating the well-fixed appearance of the femoral and tibial components.

Figure 15. Explanted femoral component with all the grooves of the male taper filled with abundant black corrosion debris.

Figure 16. Abundant corrosion on the inner taper with black corrosion debris throughout. Anterior cortical bone loss was also present, leading to the anterior porous coating of the otherwise extremely well-fixed sleeve to be exposed.

component also demonstrated corrosion at the femoral trunnion and sleeve (Figs. 24 and 25). The femoral offset adapter and locking bolt were intact, without fracture or loosening. Three months later, he was taken for stage 2 reimplant. His prior medial tibial mass had completely resolved. Short, cemented stems and cones with an oxidized zirconium (Oxinium, Smith and Nephew, Memphis, TN) femoral component were used for his revision TKA (Fig. 26). He was doing well at his 15-month postoperative visit.

Discussion

Metallosis and corrosion may be a rare but possible complication after revision TKA. Based on these cases, we believe the interface of the machined trunnion-bore tapers of the CoCr femoral or tibial components and the Ti femoral and tibial sleeves is a potential site for MACC to occur, which has not been previously reported in the literature in this system or other sleeve-based revision TKA systems. This phenomenon of taper corrosion appears to be similar to those seen in modular THA [3-11,35-39]. We have found that the addition of serum and synovial metal ion analysis may be helpful in evaluating revision TKAs with sleeves for possible corrosion as a cause of failure. In addition, radiographic findings associated with this process may include bone loss around the well-fixed sleeves or implant, which may be analogous to the medial calcar erosions that are pathognomonic for metallosis associated with MoM THA [6,40].

Failures of sleeve-based revision TKAs have previously been described with fatigue fractures at the stem-sleeve junction and at

Figure 17. Postoperative films of the fully porous stem segmental distal femur replacement. Implants appear well fixed without radiolucent lines.

Figure 18. Clinical image demonstrating the medial proximal tibial/knee soft tissue mass with the central scar left from a prior punch biopsy.

the modular implant-sleeve junction demonstrating potential areas of susceptibility [30-34,41]. Though these failures represent different locations of modular junction failure than what we are describing in this case series, we have also seen similar fractures at the modular implant-sleeve interfaces in the past. Despite a different source of metallosis than the corrosion source we are describing, we have similarly found the use of serum and synovial metal ion analysis to be helpful in the diagnostic workup of those adapter and locking bolt failures as well, especially when radiographic imaging was less than clear. Yeromosu et al. have also reported on the potential role for magnetic resonance imaging in the workup of these failures [34]. When compared to the legacy system (Sigma TC3 Revision, DePuy, Warsaw, IN), design changes have been made to include modifications to the femoral offset adapter in the current revision system (Attune Revision, DePuy, Warsaw, IN) [42,43]. While our cases and the prior case series involved the legacy revision system, there may remain concern given that the current design continues to rely on machined trunnion-bore taper junctions of CoCr femoral and tibial components against Ti sleeves, which may be a potential site for MACC to occur. Future surveillance for corrosion within these designs are necessary to better understand the true incidence of metallosis in these systems.

These cases raise the question of how to mitigate modular junction failures in revision TKA. In the setting of implant-sleeve interface fractures, one common finding appeared to be the lack of support of the distal condylar implant [30,32,34,41]. In a prior case report, the implant was used without cement due to allergy

Figure 19. Radiographs of right revision TKA with Sigma PFC TC3 revision knee system with medial tibial plateau erosions.

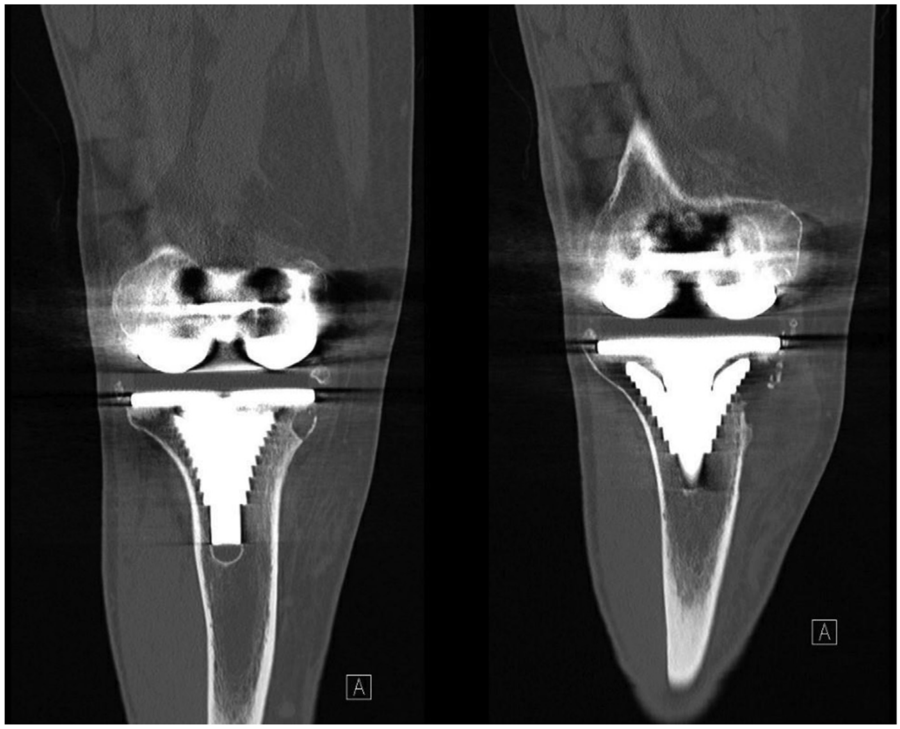

Figure 20. Computed tomography (CT) scan of right revision TKA with Sigma PFC TC3 revision knee system with medial tibial plateau erosions adjacent to the associated soft tissue mass at the medial tibial plateau.

resulting in the absence of epiphyseal support [30]. The similar failure of supportive epiphyseal cemented fixation supporting the implant may be an important risk factor of corrosion cases and could be one of the contributing factors to the risk of taper corrosion. In another report, Ihekweazu et al. [32] hypothesized that stress shielding of the distal femur resulting from sleeve ingrowth may weaken the distal cement-prosthesis interface and with ongoing cantilever cyclical loading the femoral locking bolt can fail over time as it is the weakest biomechanical link in the system.

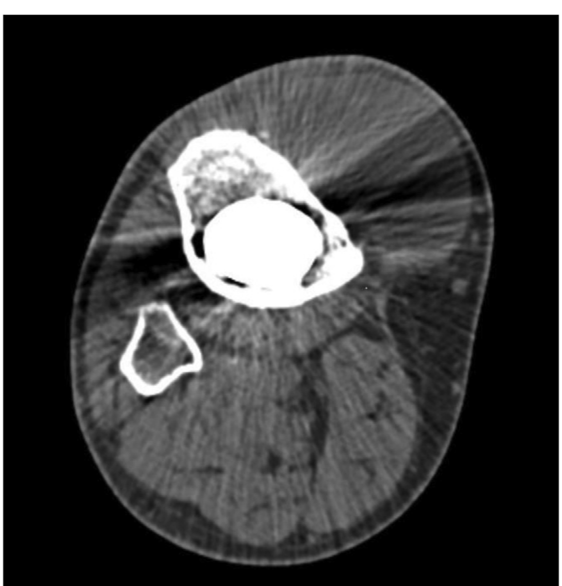

Figure 21. Axial cut of CT scan of the right knee, which demonstrates the soft tissue mass observed at patient's medial tibial plateau.

Cementation technique with a sleeve-based revision system is important. Cement interdigitation may be less than optimal in the compromised zone 1 epiphyseal bone, which can add strain on the now unsupported machined trunnion-bore taper (Fig. 27). Proper cement technique also avoids cement interposition between the porous coating of the metaphyseal sleeve and bone to prevent

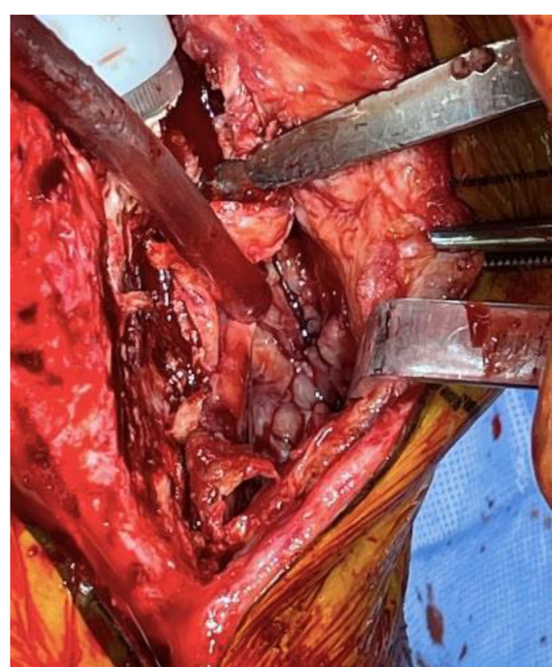

Figure 22. Clinical image demonstrating the intraoperative appearance of the pseudotumor-like medial tibial soft tissue mass.

Figure 23. Corrosion debris at the most distal end of female bore of the prior well-fixed tibial sleeve, as well as the tibial tray stem.

compromised osteointegration, which may also result in suboptimal cement pressurization to the compromised epiphyseal bone. While none of the cases in the present series were failures of the offset adapter or locking bolts, a similar lack of support may allow for stress to be applied to the machined trunnion-bore taper and aid in a process of MACC at a different modular junction than has previously been described as the source of metallosis in prior reports.

While many prior studies have focused on femoral component failures, we have also observed cases of tibial-sided sleeve corrosion, as shown in Cases 2 and 4. There are important design and mechanical differences in the implant-sleeve interfaces on the tibial and femoral sides of the DePuy Sigma TC3 revision TKA system. On the femoral side, the femoral male trunnion fits inside the female sleeve bore to engage the taper, similar to a Morse taper [44]. The male trunnion engages the female bore as far as possible to allow for an interference fit of the 2 taper angles, which causes the male trunnion to be contained within the midsection of the female bore of the sleeve. Although the tibial component of this revision TKA system still relies on the mechanical interference fit of a machined trunnion-bore taper, the tibial trunnion differs from the femoral trunnion as it passes through the entirety of the female bore taper of the MBT sleeve. The tibial male trunnion is an extension of the CoCr stem of the tibial baseplate, and it passes through the most distal extent of the Ti MBT tibial sleeve. While this tibial design difference could potentially mitigate cantilever forces, the taper remains a modular junction of CoCr (tibial baseplate) and Ti (sleeve) and may still be prone to fretting and corrosion. Additionally, stem extensions can be added to the tibial tray as opposed to the end of the sleeve, as seen on the femoral component. In the above cases of tibial-sided corrosion, there were no tibial stem extensions used. It is possible that the lack of tibial stem extensions could allow for increased risk of micromotion or fretting that could contribute to tibial implant-sleeve interface corrosion. While the potential of the unsupported distal femoral component or proximal tibial baseplate leading to increased reliance on the unsupported trunnion-bore interface of the well-fixed sleeves appears to be a potential contributing factor to corrosion on both the femoral and tibial sides, further investigation into the mechanical factors that may contribute to the corrosion in these implants is warranted.

In the revision setting of a well-fixed metaphyseal sleeve, retaining the sleeve and reusing the taper to mate a new implant has some reported success and support [41]. The patient in Case 3 may be unusual given his arthrogryposis resulting in atypical forces

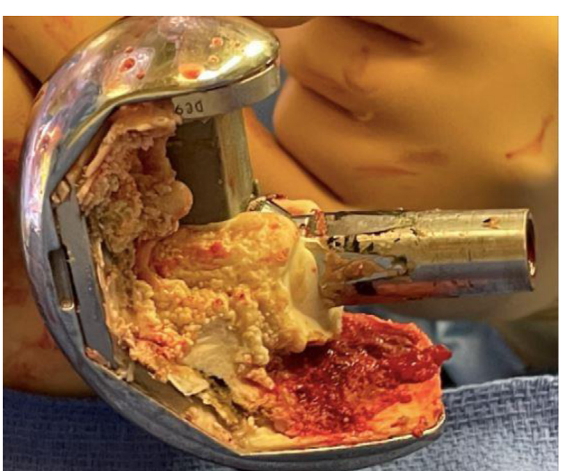

Figure 24. Removed femoral component with corrosion debris evidence at the trunnion.

Figure 25. Black etchings and corrosion debris within the bore of the well-fixed femoral sleeve after removal.

Figure 26. Postoperative anteroposterior and lateral radiographs of the most recent revision total knee arthroplasty using an oxidized zirconium femoral component along with fully cemented stems and metaphyseal cones.

on the implant. However, the well-fixed sleeve was retained and mated with a new DePuy S-ROM Noiles Hinged Femoral Component, which ultimately led to dramatic fretting, corrosion, metallosis, and bone loss. Contributing factors to the metallosis and failure may have included the increased constraint of a hinged component, the reuse of the retained sleeve and previously-used female taper, limited epiphyseal cement penetration, and inadequate or improper taper engagement. The reuse of tapers in revision of modular THAs has been demonstrated to elevate the risk of corrosion [10]. In the setting of Case 3, we took care at the revision of the constrained femoral component to a hinged femoral component to clean and dry the taper, to diligently add fully pressurized cement where possible while also avoiding getting cement interposed into the sleeve interface, and to engage the taper with significant force to seat the taper. The detectable smell after disengaging the taper may suggest that the taper indeed had been fully engaged, creating an isolated environment for the corrosion to occur. Finally, the implant design of the male trunnion of the S-ROM Noiles Hinge has a different scalloped design than the geometric flat machining edges of the Sigma TC3 male trunnion design (Fig. 15). Each of the scallops at the time of recent explant were full of black metallic debris. The scallops on the male trunnion machined taper may have some design characteristics that attempt to achieve improved rotational lock of the taper but may also allow for increased mechanical fretting and damage, an area of interest in further investigations. Finally, there was no failure of a modular offset adapter or locking bolt in this particular case, as the hinged femoral component is monolithic and does not have the modular adapter that can fail, as has been described in the constrained revision failures previously published in the literature. Our experience detailed in Case 3 has led us to approach reusing these tapers, even in the scenario of a well-fixed sleeve, with extreme caution.

Figure 27. Example of the lack of zone 1 epiphyseal segment cement fixation of femoral component.

There are several limitations to our study. As with any case report or series, we are presenting the findings of a few select cases without knowing the overall incidence of the problem. Without a denominator in the incidence equation, we cannot inform readers on the frequency of the issue of corrosion at these taper junctions or need for alarmism toward this issue. Additionally, this case series has significant variability in the ion levels that were detected, despite all cases demonstrating the visible mechanical and corrosion changes of the retrieved implants. As a result, we are unable to identify serum or synovial ion thresholds that may be concerning for corrosion. To date, there is no published literature on synovial metal ion thresholds for metallosis in TKA. Although there is published literature on metal ion thresholds in patients who have undergone MoM THA, this remains an area for further investigation as it relates to metallosis in TKA [45]. Finally, we did not perform formal laboratory implant retrieval analysis to evaluate the type and severity of corrosion in each of these cases. Instead, we have presented serum and synovial ion analysis, radiographic findings, and clinical pictures that show findings that appear analogous to the findings of MACC that have been described in the THA literature. We believe there would be value in future tribological corrosion analysis of implant retrievals to further characterize the mechanism of these failures.

Summary

The painful revision TKA can be a complex diagnostic and therapeutic challenge. We have presented a series of patients that have demonstrated findings consistent with metallosis, fretting, and corrosion of the modular machined trunnion-bore tapered junctions of a revision TKA that uses metaphyseal sleeves. We have identified the potential role of thorough evaluation for metallosis including serum and synovial metal ion analysis in the workup of painful revision TKA with sleeves. Radiographic findings associated with this process include bone loss around the implant. Additionally, advanced imaging may also reveal the presence of fluid collections or even pseudotumors, as has been described in the MoM THA literature. Further studies are necessary to accurately assess the incidence of this phenomenon.

Conflicts of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dr. Rainey has no disclosures. Dr. Archibeck is a paid consultant for and receives research support as a principal investigator from Zimmer Biomet. Dr. Anderson has been a paid speaker for Medacta in addition to being a paid consultant. He owns stock in OrthoGrid and received research support from Styker and Zimmer-Biomet. Dr. Peters receives royalties from Zimmer-Biomet and is a paid consultant. He is an unpaid consultant for Orthogrid and owns stock in this company. He serves as a board member for the Knee Society. Dr. Gilliland receives royalties from OrthoGrid and MiCare Path. He is a consultant for Stryker, Enovis, and Orthogrid possess stock in OrthoGrid, MiCare Path, and Connextions. He receives research support from Stryker, Zimmer/Biomet, and Medacta. He sits on the editorial board for the Journal of Arthroplasty and is part of the American Association of Hip and Knee Surgeons program committee. Dr. Pelt receives royalties from Total Joint Orthopedics and Smith and Nephew. He has been a paid speaker for Total Joint Orthopedics and is also a paid consultant for Total Joint Orthopedics and 3M. He owns stock in Joint Development, LLC. He receives research support from Zimmer Biomet, Peptilogics, and Smith and Nephew. He is a board member of American Association of Hip and Knee Surgeons and American Academy of Orthopaedic Surgeons.

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).

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