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Case report

Ultrasonographic and radiographic findings of polyethylene component displacement with severe metallosis and metal-induced synovitis following total knee arthroplasty

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ABSTRACT

Aseptic loosening and wear is second to only infection as the most common cause of arthroplasty failure. Degeneration of the polyethylene and metal arthroplasty components can lead to metallosis, which can cause a combination of direct cytotoxic effects and an inflammatory response within the synovial and periarticular tissues. This can result in bone resorption and secondary arthroplasty component loosening as well as a metal containing joint effusion and metal-induced synovitis. Little literature exists as to the ultrasonographic findings of metal-induced synovitis and polyethylene component displacement. As the use of musculoskeletal ultrasound significantly increases, being aware of these findings is important. The most important ultrasonographic findings include differentiating a joint effusion from synovitis utilizing dynamic compression, identifying areas of echogenic shadowing related to metal deposition and visualizing displaced arthroplasty components. The following is a case report that demonstrates the ultrasonographic imaging findings of metallosis, metal-induced synovitis and polyethylene component displacement. We will also demonstrate the ultrasound-guided aspiration findings as well as radiographic and gross pathologic correlations.

1. Introduction

Total knee arthroplasty is an orthopedic surgical procedure that provides definitive treatment for osteoarthrosis from a multitude of causes [1]. However, there remain typical surgical complications such as infection, clotting, and nerve and vascular damage as well as specific orthopedic hardware complications including fracture, prosthetic loosening, component displacement, and metallosis. Though uncommon, metallosis is relatively more prevalent in high-wear joint replacements, such as knees and hips [2,3]. Clinical concern for metallosis and subsequent appropriate imaging are key to minimizing metallic particle deposition and secondary effects on the synovium and periarticular tissues.

Radiographs are the first-line imaging modality in the post-surgical evaluation of a total knee arthroplasty and can demonstrate signs of wear and component malalignment as well as the more characteristic findings of metallosis and its secondary effects [2–7]. At our institution, musculoskeletal ultrasound (US) is most often utilized as the imaging modality following

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radiographic evaluation. The use of musculoskeletal US has significantly increased over the past decades given the ability to perform a dynamic US while interacting directly with the patient, the ease of accessibility and the lower cost when compared to magnetic resonance imaging (MRI) [8–10]. US is also preferred over MRI which is difficult to perform in patients with an arthroplasty or other metallic orthopedic hardware because of magnetic susceptibility artifacts resulting from magnetic field distortion. MRI performed in those patients requires the use of special metal artifact reduction sequences to reduce the extent and intensity of susceptibility artifacts [11].

The ultrasonographic findings of metal-induced synovitis and polyethylene component displacement are infrequently described in the literature with often only reference to the use of US to complement other modalities in the assessment of periarticular fluid collections such as joint effusions and soft tissue changes [12,13]. We present this case as it demonstrates not only the US findings of metallosis, metal-induced synovitis and polyethylene component displacement but also the US-guided aspiration findings as well as the radiographic and gross pathologic correlates.

1.1. Case report

A 62-year-old man presented for evaluation of a painful right total knee arthroplasty six years after surgery. The patient described chronic pain in his knee for three years, which was present with movement and at rest and not relieved by oral pain medications. The patient denied constitutional symptoms and did not recall any trauma after surgery.

Initial laboratory studies demonstrated the white blood cell count and C-reactive protein to be within normal limits. The erythrocyte sedimentation rate was elevated at 39 mm/Hr (normal <20 mm/Hr).

The patient was then referred for a diagnostic US of the right knee. Ultrasonographic imaging with a nine-megahertz linear transducer (GE LOGIQ E9; General Electric Company, Chicago, IL) demonstrated severe, echogenic, shadowing, and incompletely compressible distention of the suprapatellar recess consistent with severe metal-induced synovitis in combination with a complex joint effusion (Figure 1). US imaging also demonstrated the anteriorly displaced polyethylene component as an obliquely oriented linear echogenicity extending anteriorly into the infrapatellar (Hoffa) fat pad, inferior to the patella and adjacent to the patellar tendon (Figure 1). Color Doppler imaging failed to demonstrate hyperemia confirming the chronicity of this finding (Figure 1).

Radiographs were obtained which demonstrated significant dense distention of the suprapatellar recess with anterior displacement of the polyethylene component resulting in metal-on-metal articulation (Figure 2).

An US-guided aspiration of the right knee joint was requested to evaluate for an underlying infection. The US-guided aspiration was performed in the short axis utilizing an 18-gauge needle (Figure 3). The aspiration yielded approximately 250 mL of completely dark black synovial fluid (Figure 4). Synovial fluid analysis revealed a white blood cell count of 742, with cells too degenerated to identify. Fungal, aerobic, and anaerobic cultures were all negative. C-reactive protein of the synovial fluid was ≤0.4 mg/L. Alpha-defensin (Synovasure, Zimmer Biomet, Warsaw, IN) was negative.

Subsequently, the patient was scheduled for a two-stage revision total knee arthroplasty despite the absence of a proven infection. Based on the presence of extensive soft tissue destruction from the severe metallosis, the current algorithm for an infection workup was felt to be unreliable. Therefore, a staged revision, as if for a known infection, was selected in lieu of a single-stage, semi-constrained all-polyethylene component.

The femoral and tibial components as well as the displaced polyethylene liner were removed. A medial parapatellar arthrotomy was performed, and a large volume of completely black fluid was released from the capsule. The medial and lateral gutters were debrided and a portion sent for culture. Debridement down to native appearing tissue was performed. A synovectomy was performed demonstrating diffuse dark black synovial thickening typical of metallosis with metal-induced synovitis (Figure 5). Samples from the femur were sent for culture. Fungal, aerobic, and anaerobic cultures were all negative. Macroscopic examination of the retrieved prosthetic components showed severe wearing of the polyethylene liner, most pronounced posteriorly with full-thickness wear involving the underlying tibial modular baseplate and cement (Figure 6). As shown by US, the outer margins of the lateral part of the liner preserved a normal height (Figure 1). The stage-one revision arthroplasty was performed using an all-polyethylene tibial component with no modular baseplate (Figure 7). This in-situ replacement was utilized as an articulating spacer with high dose antibiotic cement holding both the femoral and all-polyethylene tibial components in place. With the use of a larger all-polyethylene tibial component in combination with post-operative bracing, the articulating spacer provided enough stability for the patient to be able to return to activities of daily living. Given the extensive soft tissue damage a semi-constrained or constrained device will be selected for the definitive arthroplasty.

2. Discussion

Total knee arthroplasty is one of the most common surgeries performed in the United States with a lifetime likelihood of seven percent in men and 9.5% in women [1]. Breakdown and loosening of components is inevitable and in the absence of infection, the most common complication is from degradation of arthroplasty components, both metal and polyethylene, and their resultant effects on the surrounding tissues [14]. Early degeneration of the polyethylene component can lead to deposition of small particles of polyethylene into the joint space and surrounding tissues, which is referred to as plasticosis. Further wear can result in metal-on-metal contact and subsequent deposition of metal products, which are predominantly oxides consistent with metallosis. This can cause local cytotoxic effects as well as an innate, adaptive, and cytokine mediated inflammatory response [14–17]. These effects can result in a large and sometimes painful joint effusion as well as resorption of adjacent bone with secondary loosening of prosthetic joint components [15,18]. Although our case demonstrated only displacement of the polyethylene component,

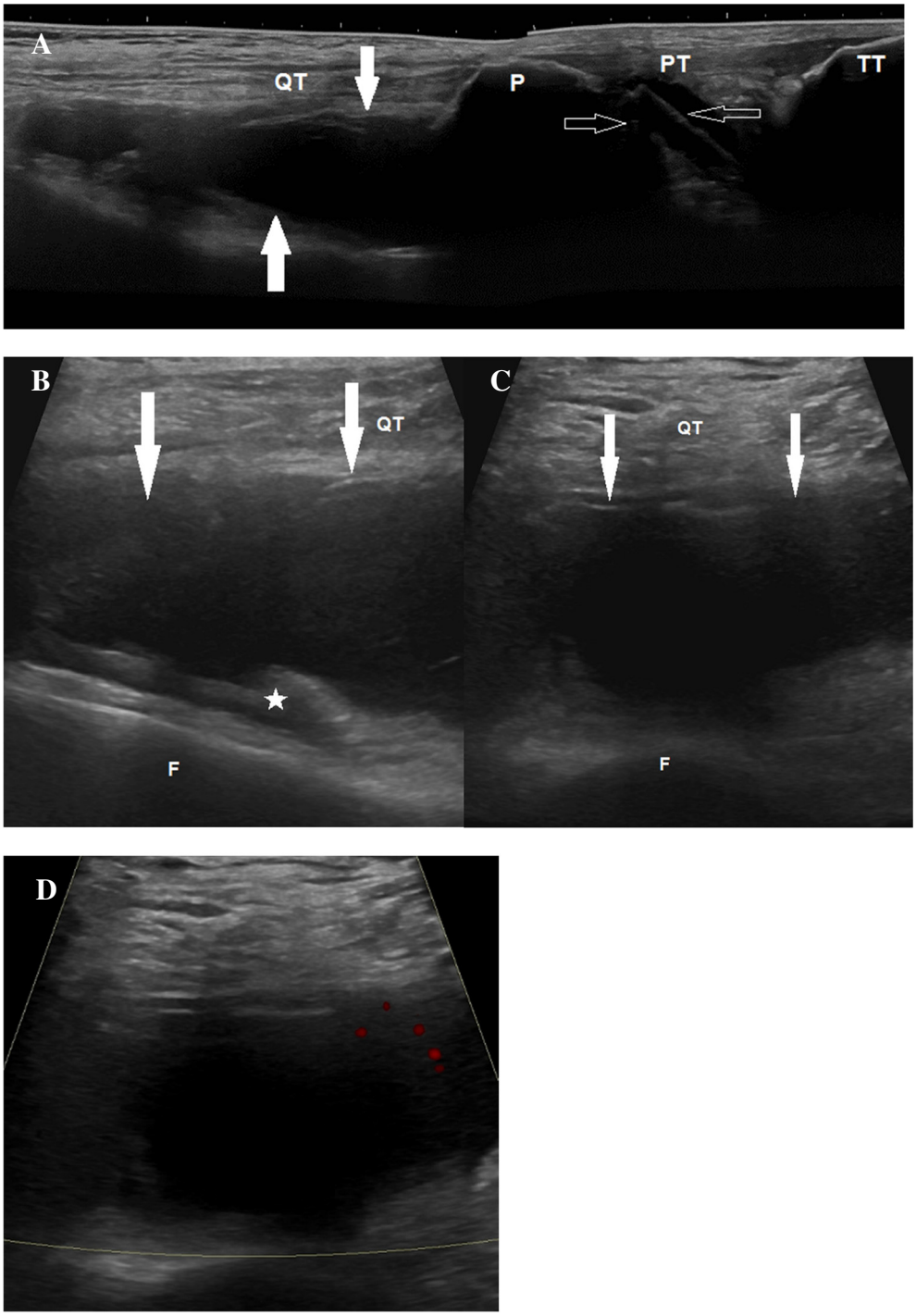


Figure 1. Ultrasonographic imaging of the anterior aspect of the right knee. (A) Panoramic long axis ultrasound image obtained with the knee in extension, at the level of the quadriceps tendon (QT), patella (P), patellar tendon (PT) and tibial tubercle (TT). Image demonstrates a massive complex echogenic suprapatellar joint effusion with multiple areas of shadowing compatible with the radiographic findings of metallic debris and metallosis (arrows). An approximately 3.8 × 0.8 cm rectangular geographic echogenicity was noted compatible with the anteriorly displaced polyethylene liner (empty arrows). (B) Long axis image at the level of the quadriceps tendon (QT) and femur (F) showing the complex echogenic suprapatellar joint effusion (arrows) and thickened synovium consistent with metal-induced synovitis (star). (C) Short axis ultrasound image at the level of the quadriceps tendon (QT) and femur (F) again demonstrating the complex joint effusion with curvilinear shadowing echogenicities compatible with metallosis (arrows). (D) Short axis power Doppler ultrasound image showing no significant associated hyperemia.

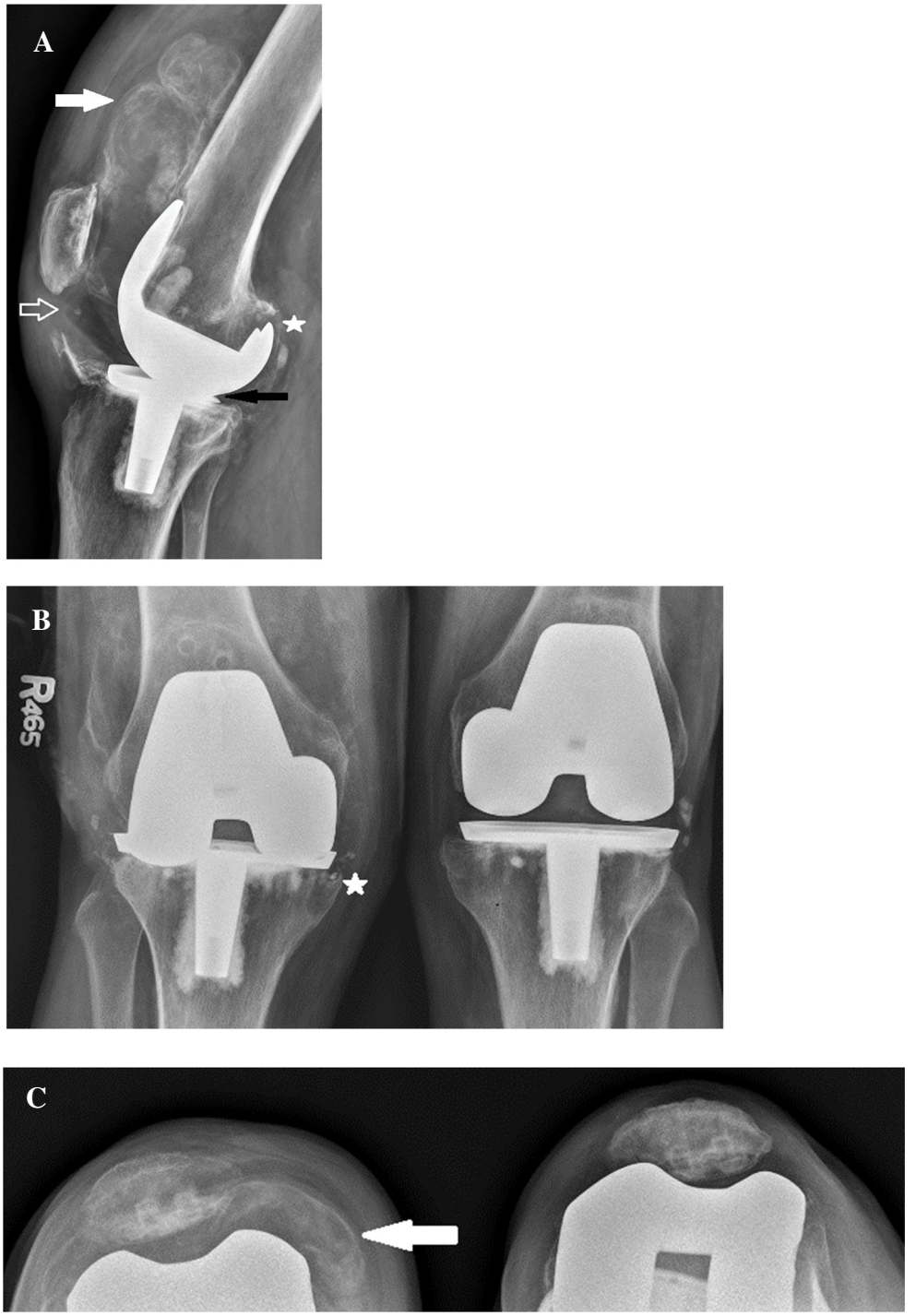


Figure 2. Radiographic appearance of polyethylene component displacement and metal-induced synovitis. (A) Lateral radiograph of the right knee demonstrating a right total knee arthroplasty with massive lobulated dense distention ('bubble sign' and 'cloud sign') of the suprapatellar recess (arrow) consistent with metal-induced synovitis and metallosis. There is also anterior displacement of the oblique disc-shaped lucent appearing polyethylene component (empty arrow) resulting in complete loss of the joint space and metal-on-metal contact (black arrow). Polyethylene wear is noted as thinning at the posterior aspect of the lucent polyethylene tray with the anterior margin demonstrating a preserved normal height. There is periprosthetic loosening of the femoral component as indicated by surrounding lucency, most pronounced at the posterior aspect of the femoral component (star). (B) Posteroanterior flexion weight-bearing radiograph of the bilateral knees shows asymmetric complete loss of the right knee joint space with again metal-on-metal contact of the femoral and tibial components secondary to the displaced polyethylene liner. Periprosthetic loosening can be seen at the medial aspect of the tibial component (star). (C) Merchant patellar view demonstrating the asymmetric right knee joint metal-induced ('metal-line sign') synovitis (arrow).

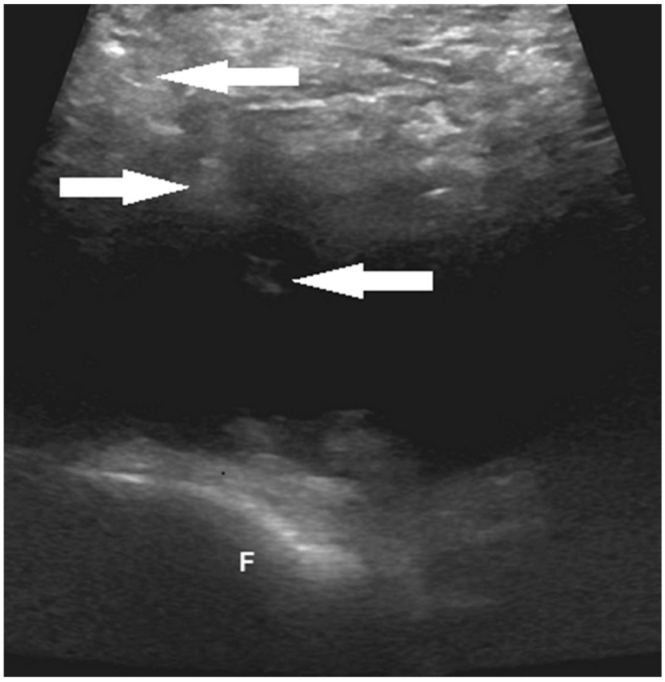


Figure 3. Short axis image obtained during the ultrasound-guided aspiration at the level of suprapatellar recess and femur (F) demonstrating the needle in-plane (arrows) with the tip in the complex joint effusion.

migration of the other components is also a known complication [19]. Migration of the patellar component is a well-known complication with some reported cases demonstrating extra-articular migration of the patellar component [20,21]. A case report by Chatterji, et al. even demonstrated a rare case of femoral component migration with complete dislodgement through an infected sinus tract, with the patient presenting after visualizing metal at the posterior knee skin surface [19].

Radiographs are the first-line imaging modality when there is concern for complications after arthroplasty and can be used to assess for the positioning and integrity of the arthroplasty components as well as the adjacent bone. Metallosis has both specific and nonspecific radiographic findings that have been described in the literature [2–7]. The more specific findings refer to the appearance of metallic density in the joint effusion or extrasynovial collection and include the 'bubble sign', the 'metal-line sign', and the 'cloud sign' (Figure 2). The 'bubble sign' is described as metal deposition outlining the entire joint space with metallic density,

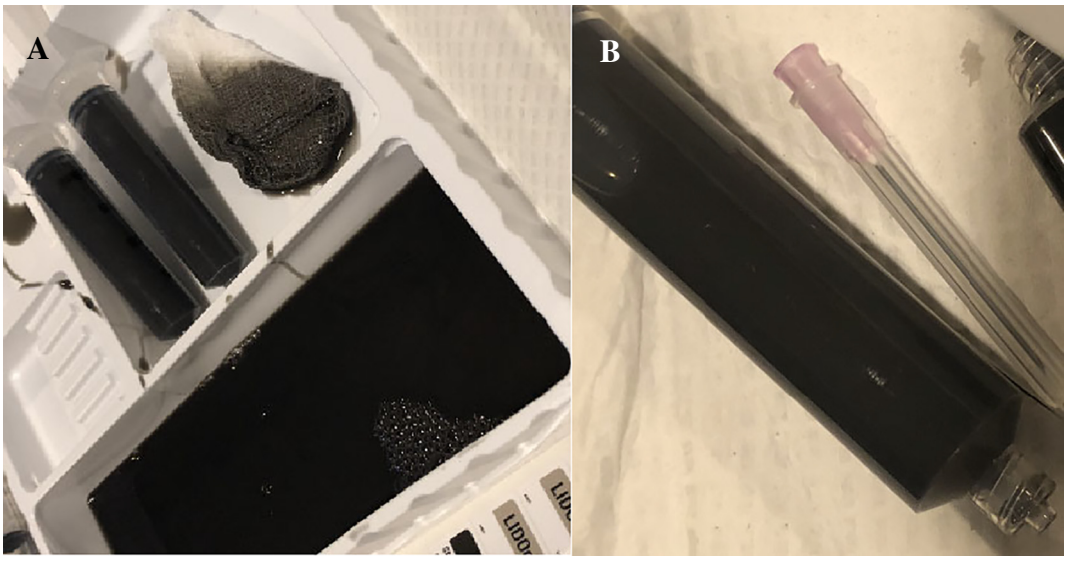


Figure 4. Photographs obtained following the ultrasound-guided aspiration of the right knee. Photographs (A) and (B) both demonstrate the extremely black color of the aspirate obtained consistent with metallosis and metal-induced synovitis.

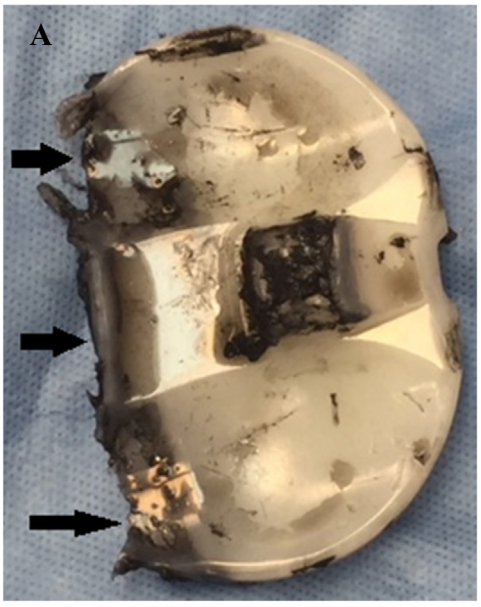
Figure 5. A synovectomy was performed demonstrating diffuse dark black synovial thickening typical of metallosis with metal-induced synovitis.

giving a curvilinear bubble-like appearance [4,5]. Similarly, a thin linear and less complete outlining of the joint capsule with metallic density has been described as the 'metal-line sign' [4,22]. The 'cloud sign' refers to amorphous fluffy or cloudy metallic densities in the joint space [4,23]. Periprosthetic osteolysis is a more sensitive but nonspecific finding that can be seen with metallosis. Computed tomography can also detect the metallic densities and is more sensitive at detecting subtle osteolysis and characterizing the full extent of bone loss for surgical planning [15].

MRI can demonstrate susceptibility artifact that would suggest metallic deposition around the joint space; however, the artifact from the arthroplasty limits its usefulness requiring the use of special metal artifact reduction sequences [7,11].

Though the US appearance of metallosis is not extensively described in the literature, knowledge of the ultrasonographic findings of metallosis, metal-induced synovitis and displacement of the polyethylene component is a must. This is especially true given the significantly increasing use of musculoskeletal US in the evaluation of knee pain and the post-surgical knee as well as its use in US-guided aspirations [9]. US of the normal anterior knee will clearly identify the extensor mechanism including the quadriceps and patellar tendons (Figure 8). Deep to the quadriceps tendon, normally only a trace amount of physiologic synovial fluid will be present in the suprapatellar recess which is present between the quadriceps (suprapatellar) and prefemoral fat pads. Deep to the patellar tendon the normal infrapatellar (Hoffa) fat pad is visualized. As in our case, a joint effusion or extrasynovial fluid collection associated with a knee arthroplasty with metallosis is readily detected by US. A recent study by Lainiala et al. demonstrated a high sensitivity and specificity for identification of pseudotumors around metal-on-metal hip prostheses [24]. The use of dynamic compressibility during US of a distended suprapatellar recess allows an advantage to both radiographs and magnetic resonance imaging in differentiating between a joint effusion and synovitis. Synovitis will not be compressible while simple joint fluid will completely compress and a complex joint effusion will partially compress or demonstrate mobile debris [9]. US also allows the real-time use of color Doppler to evaluate for hyperemia without the need for intravenous contrast administration. A heterogeneous echotexture of the fluid would be expected with the mix of necrotic tissues, inflammatory cells, and metallic as well as plastic debris. Metal deposition around the fluid collection demonstrates echogenic shadowing, as seen in our imaging, and would be the US correlate to the radiographic 'metal-line sign' and 'bubble sign' [7]. Our case is unique in that it also demonstrates ultrasonographic visualization of the displaced polyethylene component (Figure 1). Given the extent of metallosis and soft tissue destruction in our patient, the polyethylene component was likely displaced since the beginning of the patient's symptoms but never identified as he never sought medical attention until presenting to our institution. The osseous cortical contour can also be assessed on US and can identify associated osteolytic changes. In cases such as ours, it can be difficult to visualize the joint recess by US due to echogenic debris, obesity or postoperative scar tissue. In these cases we recommend decreasing the frequency of the transducer to allow deeper imaging and making adjustments in the gain to optimize visualization.

Figure 6. Photographs of the gross specimens obtained intraoperatively during the stage-one revision right total knee arthroplasty. (A) Photograph of the removed displaced polyethylene liner demonstrating severe wear, most pronounced posteriorly (arrows) secondary to the anterior displacement and compatible with the radiographic findings. (B) Photograph of the underlying tibial metallic baseplate component with fragmented cement and black synovial tissue. Severe metallic erosion is noted adjacent to the tip of the surgical probe. (C) Additional photograph of the cleaned tibial component more clearly demonstrating severe metallic erosion and metal loss along the posterior aspect (side against the blue surgical cloth) resulting in metallosis.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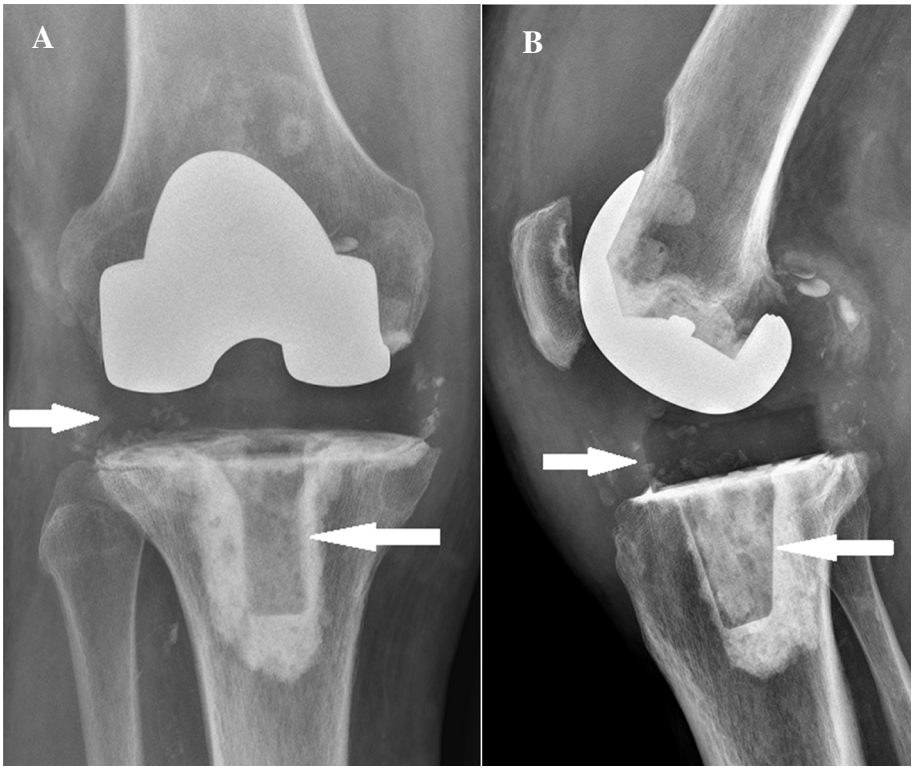

Figure 7. Radiographs obtained postoperatively following the stage-one revision total knee arthroplasty. Anteroposterior (A) and lateral (B) radiographs of the right knee demonstrating the stage-one revision right total knee arthroplasty with an all-polyethylene tibial component (arrows) and antibiotic cement functioning as a temporary articulating spacer.

When a complication related to the total knee arthroplasty is suspected based on clinical and imaging findings a prosthetic joint infection must be excluded. The infection workup, as was performed in our case, is based on a combination of serological and laboratory findings [25,26].

Serological studies include white blood cell (leukocyte) count, C-reactive protein level and erythrocyte sedimentation rate. Similar to our case, the white blood count is usually normal. Erythrocyte sedimentation rate is a nonspecific inflammatory indicator and continued elevated levels months after surgery is suggestive of an infection. C-reactive protein is an acute phase reactant which rises in response to acute injury, inflammation or infection. If elevated weeks after surgery it can also suggest an infection [25,26].

In any case of suspected periprosthetic infection a joint aspiration must be performed to evaluate the synovial fluid. Synovial fluid analysis should include cultures, gram stain, cell count, differential and white blood cell (leukocyte) count [25,26]. Laboratory-based alpha-defensin (Synovasure, Zimmer Biomet, Warsaw, IN) synovial fluid testing has also been shown to be a promising tool for diagnosing prosthetic joint infections [27,28].

Intraoperative cultures have traditionally been considered the gold standard for the diagnosis of a periprosthetic infection. Two-stage exchange arthroplasty with an antibiotic cement spacer as well as weeks of intravenous antibiotic therapy remains the most successful treatment option for eradicating an infection [25,26].

US and radiographs play a crucial role in the diagnosis of metallosis, metal-induced synovitis and a displaced polyethylene component. Knowledge of the ultrasonographic findings is important as the use of US increases for the evaluation of knee pain and the postoperative knee. The prompt recognition of both the clinical and imaging signs of metallosis is important as a delay in diagnosis can lead to an increased amount of inflammatory and cytotoxic changes in the periarticular tissues as well as continued osteolytic changes. The progression of the effects of metallosis can lead to a more complicated surgical repair.

Authors' contributions

S.M. and S.B.S. contributed to the discussion, performed the knee aspiration, researched literature, annotated images and wrote the case report. K.B. and Z.B. contributed to the discussion, researched literature and reviewed/edited the case report. W.T.N. contributed to the discussion, performed the knee surgeries, researched literature and reviewed/edited the case report.

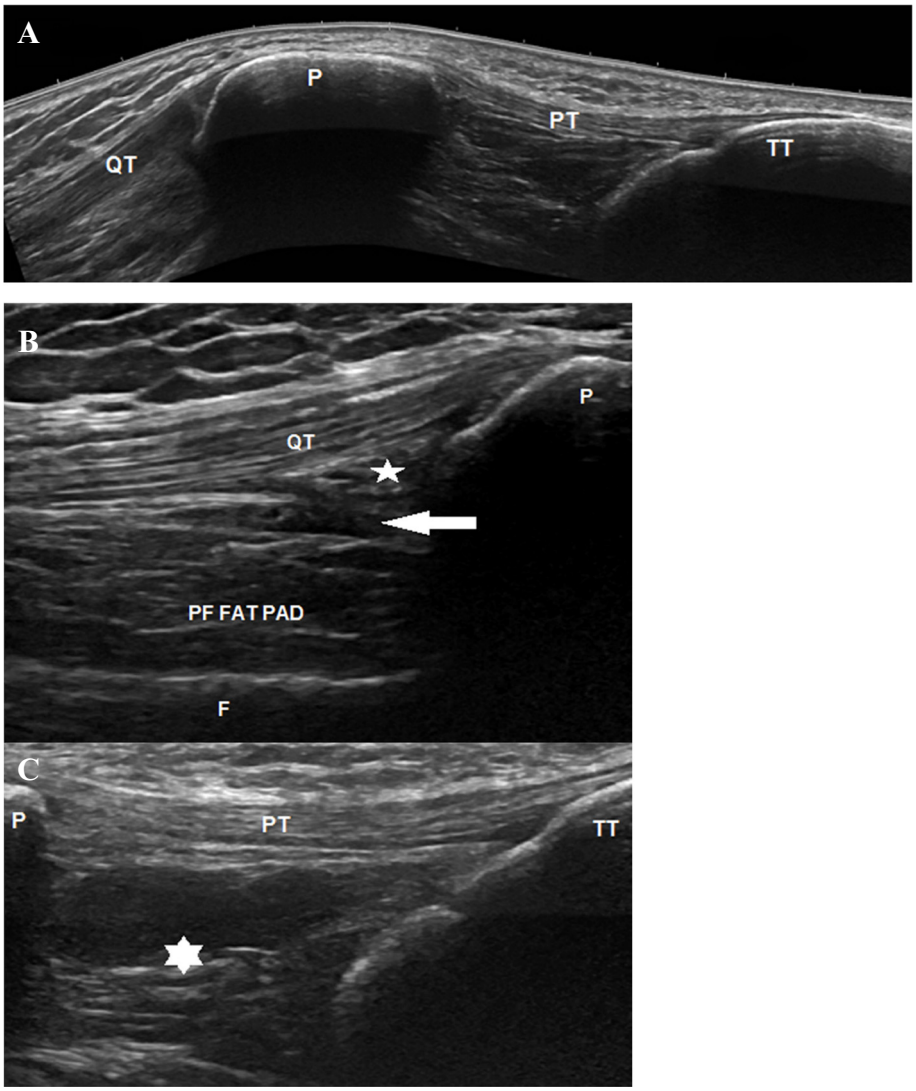

Figure 8. Normal ultrasonographic imaging of the anterior aspect of the right knee from a separate 32-year-old man. (A) Panoramic long axis ultrasound image obtained with the knee in slight flexion at the level of the quadriceps tendon (QT), patella (P), patellar tendon (PT) and tibial tubercle (TT). (B) Long axis image at the level of the quadriceps tendon (QT), patella (P) and femur (F) demonstrating normal trace physiologic fluid in the suprapatellar recess (arrow) located between the prefemoral fat pad (PF FAT PAD) and the quadriceps (suprapatellar) fat pad (star). (C) Long axis image at the level of the patella (P), patellar tendon (PT) and tibial tubercle (TT) demonstrating the normal infrapatellar (Hoffa) fat pad (asterisk).

Compliance of ethical standards

Source of support

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Declaration of Competing Interest

The authors of this case report have no conflicts of interest.

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