Metallosis After Metal-on-Polyethylene Total Hip Arthroplasty

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Abstract

Metal debris should not be generated in a well-fixed, well-functioning metal-on-polyethylene total hip arthroplasty. However, surgeons sometimes encounter periprosthetic metallosis during revision hip surgery.

Insert wear, fracture, or dislodgment in modular components may lead to articulation of the prosthetic head with the metallic shell and subsequent metallosis. Metallosis may occur with loose acetabular components as a consequence of fretting of the screws and shell screw holes or shedding of the ingrowth surface of the component. The femoral component can also be a source of metallosis: Wear of a titanium femoral head, loosening of rough surface finish from the femoral stem, and stem fracture all may result in metallic particles being deposited in periarticular tissues.

Specific clinical and radiographic findings can help in differentiating these forms of failure and in planning surgery. When metallic debris-induced bone loss is recognized early, surgical intervention may limit its progression.

Metallic debris should not be generated in a well-functioning, well-fixed metal-on-polyethylene total hip arthroplasty. However, surgeons sometimes encounter metallic debris embedded in periarticular soft tissues or implants during revision surgery. This debris can generate an intense foreign-body reaction, osteolysis, and subsequent implant failure or pathologic fracture.[1-3] Metallosis results from abrasive wear, not corrosion.[4-7] Metal debris may be generated from mode 2 wear (a primary articulating surface moving against a secondary nonarticulating surface), mode 3 wear (primary articulating surfaces moving against each other, with third-body particles interposed), or mode 4 wear (2 secondary surfaces rubbing together).[8]

In the acetabular component, wear-through,[9] fracture,[10] or dislodgment of the insert[10-16] can lead to articulation of the prosthetic head with the metallic shell and subsequent metallosis. If the acetabular component loosens, metallosis can develop as a consequence of fretting of the screws and the screw holes[12] or shedding of the ingrowth surface of the cup—which can become embedded in the articulating surface, generate third-body wear, and damage the head.[17,18] Metallosis also results from femoral stem failure: Wear of a titanium femoral head or stem,[5] loosening of rough surface finish from the femoral stem,[14,19-23] and stem fracture[24] all can generate a large volume of metallic debris.

> "Submicron polyethylene particles are the major factor in particle-induced osteolysis, unless mode 2, 3, or 4 wear patterns predominate."

The resulting metal debris is disseminated throughout the effective joint space,[25] evoking a histiocytic immune response[26] that leads to periprosthetic osteolysis. Rapid progression of osteolysis can cause a pathologic fracture or mechanical failure of the acetabular component, femoral component, or both.[12,27,28] Intensity of reaction depends on metal type, particle size and volume, rate of debris generation, and time of exposure, among other factors.[12,27-30] There is also a concern for metal ion–related hypersensitivity and toxicity[31-33]; these particles have been shown to initiate the release of osteolytic cytokines in vitro[34-36] and may also suppress expression of collagen-producing genes.[37,38]

In addition to the biologic reaction to the metal debris, metal particles (including shed ingrowth surface, broken tines for the locking mechanism, fragmented femoral stem) can become entrapped in the articulation and cause third-body wear.[39] These particles can abrade the metal and the polyethylene at the primary articulation and contribute to production of additional metallic particles and increasing polyethylene wear.[40]

In this review, we describe the various causes of metallosis in metal-on-polyethylene total hip arthroplasties and then the diagnosis and treatment strategies. Although

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our focus is on metal ion debris–induced osteolysis, it is important to note that polyethylene debris is the leading cause of joint replacement osteolysis. Analysis of tissues from osteolytic areas in patients undergoing revision total hip arthroplasty showed that submicron particles of polyethylene compose 70% to 90% of the particulate debris. Smaller quantities of titanium alloy were identified.[41] Thus, submicron polyethylene particles are the major factor in particle-induced osteolysis, unless mode 2, 3, or 4 wear patterns predominate.

Etiology

Shell-Prosthetic Head Articulation

Compared with monoblock acetabular components, acetabular modularity has the advantages of a screw-placement option to enhance initial cup fixation, use of different bearing surfaces, liners of different geometries, and ability to exchange a worn polyethylene liner.[42-44] However, modularity has the potential for articulation of the prosthetic head with the shell, which can result from liner wear-through,[9,42,43,45,46] liner fracture,[10,43] or failure of the locking mechanism with dislodgment of the insert.[10,13,15,16,47,48]

Wear-through and dislodgement of the acetabular liner (Figure 1) may be influenced by several factors, including use of a thin polyethylene insert,[9,49] sterilization with a non–cross-linking chemical surface treatment, and prolonged shelf-life for liners gamma-irradiated in air.[50-53] Engh and colleagues[9] reported on 4 cases of full-thickness liner wear-through of the S-ROM Total Hip System Polydial polyethylene liner (DePuy, Warsaw, Ind) at a minimum of 11 years after surgery. In all 4 cases, the liner was 5 mm thick and gamma-irradiated in air. Wear occurred at the dome of the cup in all cases. The locking mechanism was spared, and the polyethylene liner did not fragment. In 3 of the patients, liner and head were exchanged; in the fourth case, the component was revised because of shell damage.[9] The method of sterilization of polyethylene liners has a significant effect on liner wear rates. Liners sterilized by gamma irradiation demonstrated 0.085 mm/y less wear than those sterilized by gas plasma (a non–cross-linking chemical surface treatment).[51,52] After irradiation, inserts stored in vacuum-barrier packaging demonstrate lower wear rates, likely because of lower rates of oxidation.[53]

> **"The method of sterilization of polyethylene liners has a significant effect on liner wear rates."**

Although liners fractured often in the past, they seldom do so today. Liner fractures were reported in first-generation designs. The Acetabular Cup System (ACS; DePuy, Warsaw, Ind) polyethylene liner had a flawed design, lacking hemispherical conformity and congruence. The liner was cylindrical and thicker at the dome, with thinner polyethylene at the liner rim. Liner thickness ranged from 4.7 to 6.9 mm. Liners were sterilized by gamma irradiation in air. In a series of 94 hip arthroplasties performed with an ACS liner, 21% failed at a mean of 43 months because of catastrophic liner wear. Patients in the failure group were younger and had larger cup abduction angles with a 32-mm inner-diameter articulating surface. Wear in the failure group was 0.77 mm/y.[49] Loading at the superior rim, in an area of thin polyethylene, resulted in increased polyethylene wear and fracture of the rim of the liner and eventual failure.[49]

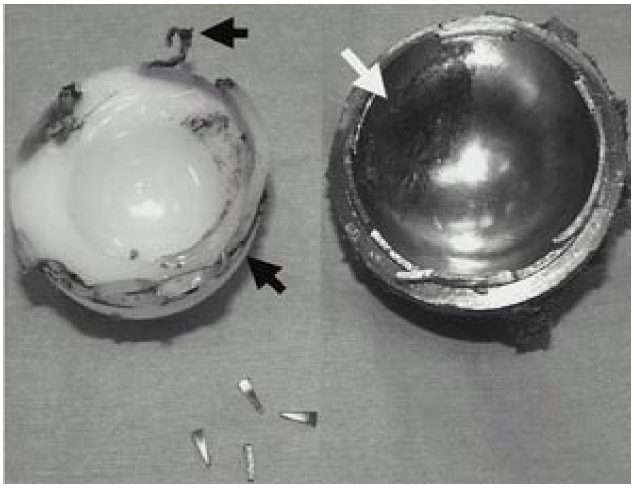

Figure 1. The deformed, fractured, and everted rim (black arrows) of a typical dislodged polyethylene liner. The metal shell demonstrates broken and bent tines and abrasion of the superolateral inner surface (white arrow) produced by articulation with the cobalt-chromium head after dislodgment of the liner. Reproduced with permission from González Della Valle A, Ruzo PS, Li S, Pellicci P, Sculco TP, Salvati EA. Dislodgment of polyethylene liners in first and second-generation Harris-Galante acetabular components. A report of eighteen cases. *J Bone Joint Surg Am.* 2001;83(4):553-559.

Failure of the locking mechanism is caused by multiple factors, including design.[54] We have found dislodgement in Harris-Galante type 1 and type 2 components (Zimmer, Warsaw, Ind) and in the Secure-Fit component (Stryker Orthopaedics, Mahwah, NJ).[11,13,16,42,48,55] Problems related to the locking mechanism have been particularly prevalent with the Harris-Galante type 1 acetabular cup design[12,13,15,47,48,55-58] and are also more likely to affect young, active, heavier patients. Between November 1995 and June 2000, 18 patients presented to the Hospital for Special Surgery with dislodgment of the polyethylene liner from Harris-Galante metal shells. Mean time in situ of the components was 7 years (range, 3-11 years). Seventeen components were second-generation, and 1 was first-generation. Symptoms developed spontaneously (n = 16), during sexual intercourse (1), or after a fall on the hip (1). Liner rims were severely damaged, and scanning electron microscopy of one fractured surface revealed a fatigue pattern (Figure 1). As this mechanism of failure includes fatigue failure of the locking tines and wear of the liner, this complication recurs as components age in situ.[13]

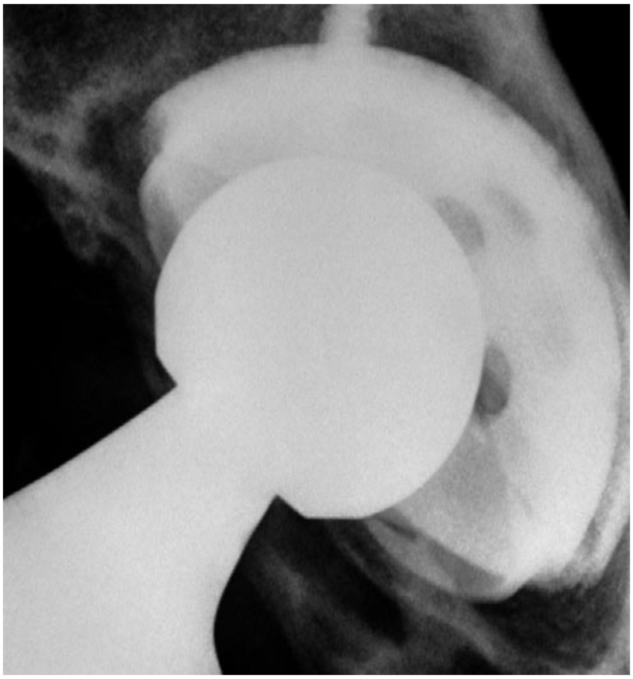

Figure 2. Fiber metal mesh shedding of a Harris-Galante type 2 acetabular cup (Zimmer, Warsaw, Ind) with periprosthetic osteolysis.

With liner dislodgement, the harder cobalt-chromium or ceramic femoral head contacts the softer titanium acetabular shell, resulting in abrasion of the shell with rapid generation of titanium particles (mode 2 wear). Rare cases of wear-through of the titanium acetabular component have occurred when revision has been delayed.

Backside Wear

Nonarticular prosthetic junctions are also potential sources of metal debris.[1] Huk and colleagues[1] examined the pseudomembrane at the liner–metal interfaces of modular uncemented acetabular components and at the screw–cup junction. This membrane contained polyethylene or metal debris in several specimens. Material from empty screw holes demonstrated a proliferative inflammatory reaction. Tissue from acetabular osteolytic lesions was histologically identical to that harvested from empty screw holes, suggesting that polyethylene and metal debris generated at the liner–cup interface may be pumped through the holes in the metal cup into the implant–bone interface.[59] The back surfaces of the liners demonstrated surface deformation and burnishing, suggesting motion between the liner and the cup (mode 4 wear).[60] Metal debris resulting from fretting between the screw head and metal cup (mode 4 wear) was identified on the back side of the liner.[1]

Metal Shedding

Bead shedding was found in first-generation cups manufactured with a cobalt-chromium bead-blasted ingrowth surface. It was prevalent in Porous Coated Anatomic (PCA; Howmedica, Rutherford, NJ) femoral and acetabular components[61] and was believed to result from poor sintering technique during cup impaction, or when micromotion developed between the implant and the bone. Chemical corrosion at the bead–shell interface has also been implicated in this phenomenon.[18] The liberated beads may cause third-body wear at the articulation (mode 3 wear). Despite improvements in sintering techniques, bead shedding has been found in modern uncemented cobalt-chromium cups. Slullitel and colleagues[17] observed radiographic evidence of bead shedding after surgery in 7 of 11 patients undergoing hip arthroplasty with the modern Vitalock Talon acetabular component (Sulzer Orthopaedics, Alton, UK).

Recently, Mayman and colleagues[62] reported on 5 patients who presented with fiber metal mesh shedding of a Harris-Galante type 2 acetabular cup 11 to 15 years after implantation. All 5 presented with hip pain, and 4 demonstrated gross acetabular loosening and fiber metal separation on preoperative x-rays. Loosening and fiber metal separation were confirmed during surgery. Progressive osteolysis was evident in the iliac bone in 4 cases. Osteolytic bone loss can lead to loss of adequate fixation, and, as the component moves, the remaining ingrown fibermesh detaches from the loose component[62] (Figure 2).

Femoral Loosening

The surface finish of cemented femoral stems has been shown to contribute to generation of metal debris (mode 3 wear). Proximally roughened[19,21,63-65] or precoated[22,24,66,67] stems, designed to maximize bonding by providing mechanical interlock between the implant and the cement, have shown a high rate of early failure caused by aggressive femoral osteolysis and aseptic loosening.[4,5,20,21,23,66-69]

> "The surface finish of cemented femoral stems has been shown to contribute to generation of metal debris (mode 3 wear)."

We have reported a high failure rate (11% of 64 stems revised for aseptic loosening at a mean of 5.9 years) in the rough (Ra 1.75-2.5µm) VerSys cemented femoral stem (Zimmer, Warsaw, Ind)[19] and in the Spectron EF stem (Ra 7.3µm; Smith & Nephew, Memphis, Tenn) (15 stems revised for aseptic loosening at a mean follow-up of 6.8 years).[20] Once loosening occurred, micromotion and macromotion of the rough surface stem against the cement mantle rapidly generated cement and metallic debris.[19] In addition to producing biologically active metal and cement particles, this process decreases the conformity between implant and cement, which accelerates loosening and bone loss.[4,5,20,69-72] This form of failure is rare in polished surface finish implants.[73,74]

Diagnosis of Metallosis

Clinical Symptoms

There may be no specific signs or symptoms that indicate metallosis, which can be suspected only after careful review of history, signs, and symptoms associated with multiple previous causes of failure. Wear-through of the polyethylene liner, liner fracture, or dislodgment can be suspected on the basis of clinical and radiographic findings. An eccentric femoral head will be evident in all cases. If these conditions are diagnosed and treated late, the head can wear though the shell and generate massive osteolysis. Some clinical features are distinctive of each condition.

Liner wear-through progresses slowly and is usually noncatastrophic and mostly asymptomatic. If hip pain is present, it is most likely secondary to periprosthetic osteolysis and to the inflammatory response to polyethylene debris.[9] Some patients may have an audible crepitus or squeaking on weight-bearing, between the femoral head and the shell. Most patients have not been seen for routine follow-up for several years.

Stem fracture, liner fracture, and liner dislodgment can usually be identified by patients at the moment of occurrence. Symptoms can develop spontaneously or can be associated with a fall on the hip, with sexual intercourse, or with rising from a squatting position.[10] With dislodgement, patients often experience new-onset hip pain and difficulty with weight-bearing, which may be accompanied by clicking, limb shortening, or decreased range of motion.[13]

Screw fretting, metal shedding, and third-body wear from metal debris are much more difficult to diagnose on physical examination. Careful review of serial annual x-rays is critical for diagnosis of these cases.

Radiographic Signs

Several radiographic signs may assist in the diagnosis of metallosis. In cases of liner dislodgement or major polyethylene wear, a femoral head eccentrically positioned within the cup should be evident (Figure 4). A curved radiolucency under the femoral neck representing the dislodged insert may also be appreciated (Figure 4).[13] Broken tines may suggest recent or impending dislodgement of the polyethylene liner (Figure 4).[10,13] A broken tine detected on routine follow-up x-rays in an asymptomatic patient suggests a need for education about decreasing weight-bearing activities and careful discussion of the possibility of future liner fracture or dislodgement and accompanying symptoms.[9]

The radiographic finding is a worn-through liner, which may resemble a dislocation. In several patients, closed reduction of assumed dislocations was attempted when the cause of the pseudodislocation was dislodgement of the acetabular insert. Depending on time from event to diagnosis and on patient activity level, x-rays may show varied degrees of metallosis and subsequent osteolysis.

In cases of severe metallosis, deposition of metal wear debris results in opacification of the periprosthetic soft tissues and delineates the effective joint cavity, producing a radiographic bubble sign (Figure 5).[12,58] This finding indicates severe metallosis and suggests urgent revision. X-rays may also show periacetabular radiolucent zones indicating osteolysis[12] and metal particles.[12]

Joint Aspiration

The diagnosis of metallosis may be confirmed by hip aspiration, which yields dark gray or black synovial fluid.[9,10] The color change has been seen only days after onset of acute symptoms,[13] making hip aspiration an immediate and sensitive diagnostic procedure.

Figure 4. Metallic debris on x-ray. Anteroposterior x-ray of hip shows eccentric positioning of femoral head, broken tine, and curved radiolucency below femoral neck representing dislodged polyethylene liner (arrow). Reproduced with permission from González Della Valle A, Ruzo PS, Li S, Pellicci P, Sculco TP, Salvati EA. Dislodgment of polyethylene liners in first and second-generation Harris-Galante acetabular components. A report of eighteen cases. *J Bone Joint Surg Am*. 2001;83(4):553-559.

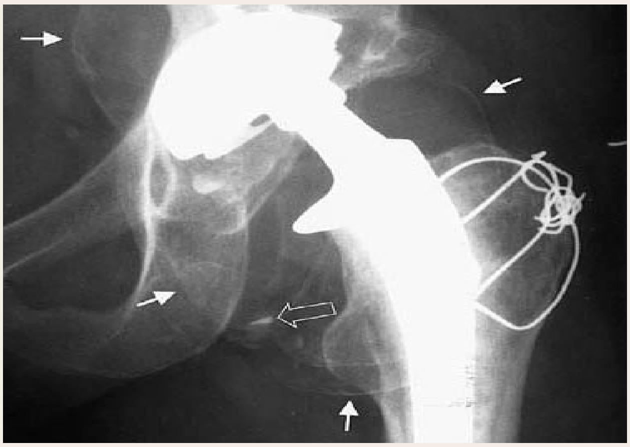

Figure 5. The bubble sign. Closed arrows delineate effective joint space outlined by metallic debris. Open arrow shows a broken tine. Reproduced with permission from Su EP, Callander PW, Salvati EA. The bubble sign: a new radiographic sign in total hip arthroplasty. *J Arthroplasty*. 2003;18(1):110-112.

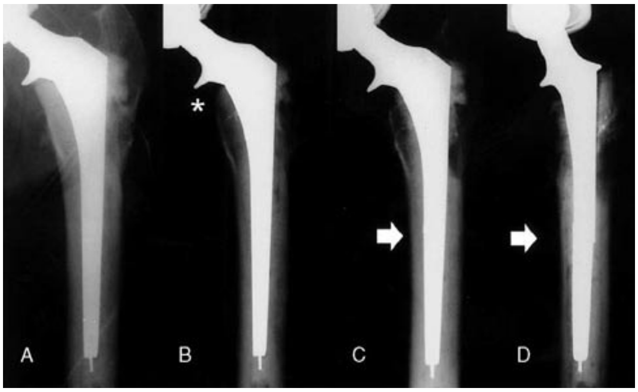

Figure 3. Fracture of a cemented cobalt chrome stem. Serial x-rays of hip of woman with body mass index of 20. **(A)** Postoperative x-ray shows cemented femoral stem with appropriate stem size, alignment, and cementing technique. **(B)** One year after surgery, loss of calcar support is seen (asterisk). Five years after surgery, a fracture in the midportion of the stem is seen on anteroposterior **(C)** and lateral **(D)** x-rays. Reproduced with permission from Della Valle AG, Beksaç B, Anderson J, et al. Late fatigue fracture of a modern cemented [corrected] cobalt chrome stem for total hip arthroplasty: a report of 10 cases [published correction appears in *J Arthroplasty*. 2006;21(7):1082]. *J Arthroplasty.* 2005;20(8):1084-1088.

Stem Fracture

Fatigue fracture of femoral stems may generate metal debris, particularly when revision surgery is delayed (mode 3 wear) (Figures 3A–3D). We recently reported on 10 fatigue fractures of the Omnifit stem (Osteonics, Allendale, NJ), a cemented, forged cobalt-chromium alloy stem.[75] Fractures presented spontaneously at a mean of 8 years after surgery with hip pain. Excessive weight (8 patients had a body mass index of more than 25) coupled with loss of proximal medial calcar support (7 patients) may have resulted in the stem bearing the majority of the cyclic loads applied to the hip, eventually leading to fatigue fracture.[75] Eight patients underwent revision surgery; the other 2 were advised to proceed with revision surgery but had not yet scheduled it.[75]

Treatment: Results of Revision Surgery

Effective treatment requires revision surgery to remove metal debris, to bone-graft areas of osteolysis, and to address the mechanical failure. At revision, surgeons may see black fluid filling the effective joint space as well as grayish periprosthetic tissues, suggestive of metallosis (Figures 6A–6C). When the process is secondary to an acute event (eg, liner dislodgement), degree of metallosis is directly proportional to time from symptom onset to revision.[13] In cases caused by polyethylene wear-through, eccentric, superolateral erosion and fraying of the liner may be noted. Fractured polyethylene inserts typically have everted rims and markings consistent with fatigue. Embedded metallic debris may be noted in the polyethylene (Figure 7). With liner fracture or complete wear-through, the softer inner surface of the titanium shell becomes blackened and abraded from articulation with the harder cobalt-chrome femoral head, eventually resulting in shell penetration (Figure 8). Backside wear may manifest as scratching and absence of machine lines on the convex surface of the insert.[13] Femoral component subsidence may also be observed, with polishing at all 4 facets, especially the posteromedial and

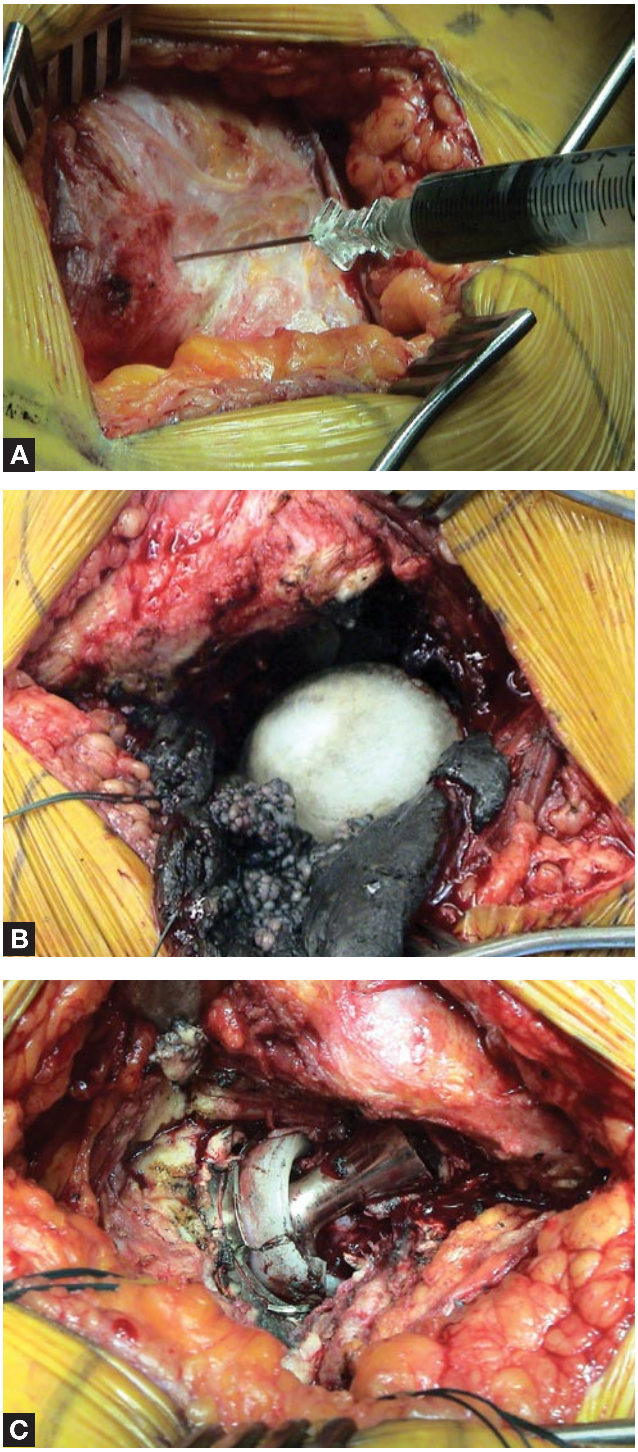

Figure 6. Metallosis in vivo. Intraoperative photographs at revision hip surgery show **(A)** black fluid aspirated from hip joint; **(B)** black fluid filling joint space, metallic staining of periprosthetic tissues, and polyethylene liner dislodgement; and **(C)** extensive metallic debris, polyethylene liner, and acetabular shell damage.

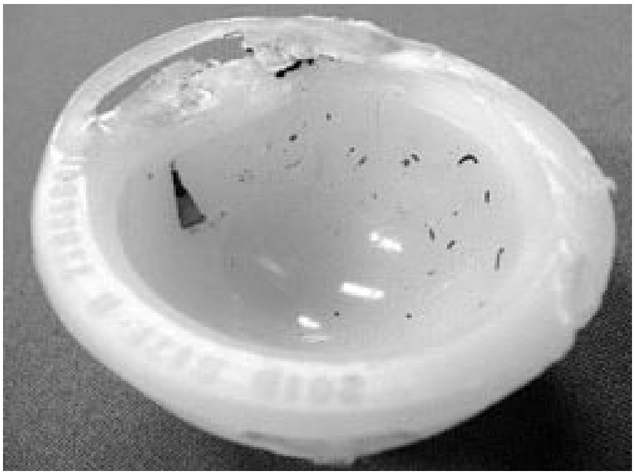

Figure 7. Tines embedded in polyethylene. Retrieved polyethylene liner after revision for metallosis. Note rim damage and metal tine embedded in liner.

Figure 8. Worn-through shell. Retrieved acetabular component after revision for metallosis shows complete wear-through.

anterolateral corners.[19,20,70] Metallic debris embedded in tissues can be very difficult to remove and often resembles tar. Removing all metal debris can be difficult and dangerous, as complete excision may compromise key osseous and neurovascular structures and tendon attachments, particularly the gluteus medius tendon. Histologic evaluation has shown that periprosthetic tissues affected by metallosis contain metal, polyethylene, and cement particles and are marked by an intense inflammatory response characterized by histiocytes and giant cells.[27]

Acetabular and/or femoral component revision for metallosis has demonstrated good results at intermediate-term follow-up, with no evidence of osteolysis or cup migration.[12] Chang and colleagues[12] reported on 31 patients noted at revision surgery to have hip joint metallosis. At a mean follow-up of 5.6 years, none of the revised hips demonstrated radiolucent lines, acetabular cup migration, osteolysis, or change in inclination. Replacement of the polyethylene liner, débridement of osteolytic lesions, and bone grafting with allograft chips are effective the first 5 years after revision surgery if the implant was not loose at revision.[9,12,13] If the implant is well fixed, leaving metallotic tissue appears not to affect the long-term results of revision surgery for metallosis.

"Metallic debris embedded in tissues can be very difficult to remove and often resembles tar."

At revision surgery, if the shell is well fixed and in good position, the low-demand patient may benefit from having a new all-polyethylene cup cemented into the existing shell if it has holes.[13] Both the shell and the liner should be textured to allow for cement–shell interdigitation.[76,77] Shell revision is recommended if acetabular bone quality and stock are good, if the cup is misaligned or laterally positioned, or if the shell diameter is too small for cementing an all-polyethylene cup within it, not allowing for a sufficient cement mantle or polyethylene thickness. Ideally, polyethylene inserts at least 6 mm thick should be used to replace damaged liners. If the stable femoral component is modular, the head may be downsized, thereby allowing for increased thickness of the insert. There is an increased risk for dislocation with revision surgery because of several factors, and this risk must be discussed with the patient.

Revision of the femoral stem may also be necessary if it is loose. In well-fixed and well-positioned stems, good results have been reported after curettage and bone grafting of localized osteolytic lesions surrounding the proximal part of the femoral stem.[12] Complete removal of all metal debris is difficult, as it may result in extensive tissue damage.[12,58] Complete removal of metallic debris is not necessary for implant stability. Critical aspects of the operation are thorough débridement and bone grafting of osteolytic lesions and revision of loose components.[12]

Occasionally, removal of a well-fixed stem may be helpful to provide adequate exposure of the acetabulum.[78] It is not necessary to remove a well-fixed cement mantle; it may be roughened with a burr, and new cement may be inserted in the liquid phase to prevent lamination and enhance bonding. In the absence of evidence of damage, some authors have cemented into the existing cement mantle the same extracted stem.[79,80]

As metallic fatigue cannot be determined, we prefer to cement a new stem into the retained cement mantle. We have reported on 19 revision hip arthroplasties in which a new femoral stem was cemented into the old cement mantle. At a mean follow-up of 59 months, no stem had been revised for loosening, and all stems were radiographically stable.[79,80]

Alternatively, Nabors and colleagues[78] reported good results impacting the old stem into the existing cement mantle without adding new cement. Forty-two hips that underwent reinsertion of a cemented femoral component during isolated acetabular revision demonstrated good results at a follow-up of 67 months. Only 2 femurs were loose, but both were asymptomatic, suggesting that this technique can improve acetabular exposure with a low risk of femoral stem loosening.

Conclusions

Metallosis, resulting from articulation between nonbearing surfaces or third-body wear, is seen with total hip arthroplasty implant failure. As most causes of metallosis are "time-dependent," the frequency of metallosis may increase over time. Certainly, improvements in design and tribology have reduced incidence in modern components. Routine follow-up is ideal, and earlier detection of the condition by orthopedic surgeons is essential, as earlier limited surgical intervention can prevent development of severe osteolysis and gross implant loosening necessitating more complex revision.

Authors' Disclosure Statement

The authors report no actual or potential conflict of interest in relation to this article.

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