Journal of Clinical Orthopaedics and Trauma 11 (2020) 9–15

Contents lists available at ScienceDirect

Journal of Clinical Orthopaedics and Trauma

journal homepage: www.elsevier.com/locate/jcot

Revision total hip arthroplasty for metal-on-metal failure

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ARTICLE INFO

Article history:
Received 21 August 2019
Accepted 26 September 2019
Available online 4 October 2019

Keywords:
Revision hip arthroplasty
Metal-on-metal failure
Hip resurfacing

ABSTRACT

Metal-on-metal (MoM) arthroplasty systems became popular in the early-2000s due to presumed advantages of improved wear characteristics and superior stability. However, subsequent reports of abnormal soft-tissue reactions to MoM implants and national registry data reporting high failure rates raised concerns. Early outcomes of revision total hip arthroplasty (THA) for adverse reaction to metal debris (ARMD) were poor, leading to development of surveillance programs and a trend towards early revision surgery. Patients with MoM arthroplasties require surveillance, comprehensive history and physical examination, imaging with ultrasound or magnetic resonance imaging (MRI), and laboratory evaluation including metal ion levels. Operative strategies for revision THA vary from exchange of modular components to extensive debridement and reconstruction with revision components. Surgeons should be aware of the increased risks of dislocation and infection following revision THA for ARMD. However, there is growing evidence that early revision surgery prior to extensive soft tissue destruction results in improved outcomes and decreased re-operation rates. It is estimated that >1 million MoM articulations have been implanted, with a large proportion still in situ. It is imperative to understand the aetiology, presentation, and management strategies for these patients to optimise their clinical outcomes.

1. Introduction

McKee and Watson-Farrar introduced the first metal-on-metal (MoM) total hip arthroplasty (THA)[1] in the 1950's. However, these initial implants became obsolete as the Charnley technique of low-friction arthroplasty with metal-on-polyethylene bearing surfaces gained popularity in the mid-1970s.[2] Subsequent generations of MoM implants using cobalt-chromium-molybdenum alloys provided optimism due to theoretical advantages over conventional metal-on-polyethylene bearing surfaces.[3] Implantation of thinner metal liners with larger femoral head sizes increased the arc of motion and promised decreased dislocation rates.[4] In addition, improved wear characteristics and reduced volumetric wear with MoM bearing surfaces provided a potential advantage over metal-on-polyethylene in decreasing the risk of osteolysis associated with polyethylene wear.[5] This led to increased interest and reintroduction of hip resurfacing, which offered an additional benefit of bone preservation on the femoral side.[6]

These proposed benefits led to increased appeal and widespread uptake of both MoM THA and hip resurfacing. This popularity peaked in the early 2000's, where 35% of all THA utilised MoM bearing surfaces in the United States.[7] However, subsequent reports of abnormal soft-tissue reactions to MoM implants and national registry data revealing unacceptably high revision rates raised concerns.[8–12] The Medicines and Healthcare Products Regulatory Agency (MHRA) in the United Kingdom issued an alert in 2010 highlighting reports of reivions of MoM hip arthroplasties involving soft tissue reactions.[13] Subsequent action included the development of surveillance programs to ensure routine follow-up and investigations with serum ion levels and imaging.[13] In 2011, The United States Food and Drug Administration (FDA) mandated that manufacturers of MoM THA and hip resurfacing systems perform post-market surveillance and publicly addressed growing concern for abnormal soft tissue reaction and increased revision rate.[14]

Although MoM THA and hip resurfacing are both associated with ARMD, they have different aetiologies.[15] MoM THA is associated with taper corrosion leading to deposition of metal ions in the peri-prosthetic space, often without significant wear of the bearing surfaces. In contrast, ARMD in hip resurfacing is generally secondary to wear of the MOM articulation. It is estimated that the risk

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https://doi.org/10.1016/j.jcot.2019.09.021
0976-5662/

of ARMD following hip resurfacing ranges from 0.3% to 3.4% with a maximum mean follow-up of 7.1 years.[8,15,16] Outcomes following hip resurfacing also depend on the implant design, with the Birmingham resurfacing (BHR, Smith & Nephew) outperforming the ASR surface replacement (DePuy). This has led to a recall of specific MoM implant systems including the DePuy ASR XL Acetabular system, Smith & Nephew R3 Acetabular system metal liners, and the Zimmer Durom Acetabular component.[3] It has been reported that up to 18% of patients implanted with the DePuy ASR THA system had developed ARMD.[16] However, these reported figures may grossly underestimate the true prevalence, with one study identifying pseudotumours in 59% of patients with MoM hip prosthesis using metal artifact reduction sequence (MARS) magnetic resonance imaging.[17]

Initial outcomes following revision surgery for MoM implants were poor.[18] However, these were often performed in the setting of significant soft tissue damage and pseudotumour. It is evident that outcomes following revision surgery is dependent on the indication, with worse outcomes demonstrated with the presence of pseudotumour and abductor deficiency.[15] This had led to improved surveillance and adoption of a lower threshold for revision THA.[8,15,17]

This has led to a cessation of MoM bearing surfaces for THA and a significant decrease in the number of hip resurfacings performed annually. In 2017, the NJR in the UK reported <0.1% of all hip replacements utilised MoM bearing surfaces. It also reported a decreasing percentage of implanted hip resurfacings (0.6%) compared to all primary hip arthroplasty.[19] Despite this, a sizable patient population have MoM implants in situ, and it is estimated that >1 million MoM articulations have been implanted worldwide.[3,7] It is imperative to understand the aetiology, presentation and management strategies for these patients to optimise their clinical outcomes.

2. Aetiology

The deposition of metal ions into the peri-prosthetic space can lead to a wide spectrum of soft tissue reactions including massive sterile effusions, necrosis, corrosive osteolysis, and both cystic and solid peri-prosthetic masses. This spectrum of soft tissue lesions associated with MoM articulations is collectively labelled as adverse reaction to metal debris (ARMD).[12] ARMD also encompasses the terms metallosis, aseptic lymphocytic vasculitis-associated lesions (ALVAL), and pseudotumour, which have all been used to describe the various presentations.[20,21] Metallosis describes gross macroscopic staining of peri-prosthetic tissues secondary to metal particulate debris.[20] ALVAL is a specific histological diagnosis that exhibits a lymphocyte dominated immunological response and can occur throughout all severity and stages of ARMD.[21] Pseudotumour refers to a peri-prosthetic soft tissue mass that typically is associated with widespread tissue necrosis and ALVAL.[12] The mass itself has been described as cystic, solid, or a combination of both.

The abnormal soft tissue reaction to MoM bearing surfaces results from the deposition of cobalt-chrome particulate debris in the surrounding tissues.[22] This is thought to be secondary to corrosive metal contact between the cobalt-chrome femoral head and metal liner, which leads to release of metal ions.[23] Risk factors for increased wear and metal debris include malpositioned acetabular components with an increased abduction angle ($\geq 50^{\circ}$) and anteversion leading to edge loading and failure of lubrication.[23] It is also increasingly apparent that metal ion release can result from abnormal corrosion between the cobalt-chrome head and trunnion.[15,24,25] Multiple studies have identified corrosion on retrieved femoral components without any evidence of significant wear of the MoM bearing surfaces.[26,27] The additional head-trunnion junction present in MoM THA (compared to MoM hip resurfacing) may exacerbate and accelerate the problems associated with MoM bearing surfaces.[28,29] A randomised control trial comparing large-head MoM THA and hip resurfacing demonstrated higher serum metal ion levels in the THA group, with no clear effect on outcomes.[28]

Previous in vitro studies proposed that metal particulate debris induced a dose-dependent local cytotoxic response and necrosis in the peri-prosthetic soft tissues.[30] This remains controversial, as recent literature suggests no association between periprosthetic tissue metal content and histological findings.[31] A delayed type IV hypersensitivity reaction has also been implicated as a possible cause of tissue damage in the absence of significant wear or corrosion, with similar histological findings to perivascular lymphocyte infiltration.[32] However, this potential aetiology remains debatable as true hypersensitivity is rare and the majority of cases with ALVAL can be explained by excessive wear or corrosion.[32,33]

Release of both metal ions and nanoparticles occur following abnormal wear of MoM articulations. Metal particulate debris has increased bioactivity, quantity of particles, and surface area compared to the classic larger particles from polyethylene wear.[15] The metal particles are then phagocytosed by giant cells and macrophages, which leads to a release of intra-cellular metal ions and subsequent cell death.[15] Macroscopically, this can manifest as soft tissue destruction, aseptic loosening, and osteolysis.[15]

Local metal debris is also associated with increased serum ion levels. These levels may become grossly elevated with progressive implant loosening. Studies have demonstrated systemic dissemination of metal particles in solid organs, although its clinical relevance is largely unknown. Increased exposure to cobalt and chromium has induced teratogenicity in animal models, but there is no conclusive evidence that this occurs in humans.[34] Regardless, the theoretical possibility of long-term effects, combined with lack of available literature, provides an indication for ongoing surveillance of these (often) young patients.

3. Presentation & evaluation

Patients with implanted MoM THAs or hip resurfacings require routine surveillance including a detailed history, physical examination, imaging, and bloodwork. Patients can be broadly divided in 2 distinct categories with different treatment algorithms: (1) asymptomatic and (2) symptomatic.[3] A comprehensive history is imperative to identify current symptomatology including assessment of pain onset, severity, frequency, character & location. A detailed review of the index operation and immediate postoperative course is also important, in particular the specific implant type, surgical approach and history of wound complications. Attention should be made to rule out any evidence of local and systemic infection. While the true relationship between metal allergy and ARMD is uncertain, patients should be asked if there is a history of personal or family history of metal allergy.

Routine physical examination includes assessment of gait and strength testing of the abductor muscles. Previous surgical incision(s) should be inspected for signs of infection and the hip should be palpated to identify any obvious soft tissues masses.[3] Evaluation of range of motion and detailed neurovascular examination can help rule out other pathologies causing a painful hip. A careful history and physical exam determines the role of subsequent imaging and laboratory testing.

4. Imaging

Plain radiographs of the pelvis and affected hip should be

reviewed to identify the implant type, size, and component position. Serial radiographs should be compared for evidence of progressive osteolysis, subsidence, and change in component position. Progressive osteolysis in the ischium, pubis, or retroacetabular regions may indicate more extensive disease with associated component loosening.[3] Fracture of the femoral neck (specifically for hip resurfacing) and aseptic loosening can often be identified with plain radiography, but do not necessarily confirm underlying ARMD.[15]

The acetabular abduction angle should be carefully measured, as abduction angles $\geq 50^{\circ}$ have been associated with increased synovial and serum metal ion levels, likely secondary to edge loading.[23] It is also important to recognise that the large-diameter metal femoral heads may obscure the acetabular rim, decreasing the validity of plain radiographs for assessing acetabular position.[35]

Both ultrasound and metal artifact reduction sequences (MARS) magnetic resonance imaging (MRI) are acceptable cross-sectional imaging modalities to detect ARMD. Ultrasound is a cost-effective, quick, readily available, and non-invasive imaging test that is reliably able to detect pseudotumour. It is can also identify lesions as cystic or solid and is relatively unaffected by the presence of metal implants. It is the preferred modality for patients with contraindications to MRI, and can also be used to guide hip aspiration for histological and culture analysis.[15] Ultrasound has been shown to have a sensitivity of 100% and specificity of 96%.[36] A disadvantage of ultrasound is that it is user-dependent and can be challenging to evaluate deep structures. In addition, the quality of imaging can be significantly affected in obese patients, reducing its utility.

MARS MRI offers the ability to assess both the soft tissues and bone in the peri-prosthetic space. Advocates for MRI believe it offers an improved assessment of the extent of soft tissue damage, quality of the abductor tendons, and surrounding musculature. It is also easier to compare serial MRIs for assessing progression of disease. The sensitivity and specificity of MRI has reported to be 92% and 100%, respectively.[36] However, despite the use of metal artifact reduction sequences, prosthetic artifact can still occur and small lesions can be missed.[15] MRI is also significantly more costly than ultrasound (estimated £216 vs. £49) and generally less available.[37]

CT scans can be useful to accurately determine component position and assess the degree of osteolysis and residual bone stock. However, it is not as reliable as ultrasound or MRI in delineating soft tissue lesions.

The decision to perform an ultrasound versus a MARS MRI as the initial screening tool remains controversial, with no obvious consensus. The United Kingdom Medicines and Healthcare Products Regulatory Agency (MHRA)[38] recommends either ultrasound or MRI as an effective imaging modality. Garbuz et al. recommended ultrasound as an initial screening tool, citing decreased costs and the ability to reliably rule out pseudotumour in asymptomatic patients (sensitivity 100%).[36] Other authors have advocated for obtaining both MRI and US when revision surgery is planned, suggesting that combined imaging is the most effective method to identifying the presence of pseudotumour.[39] The decision to perform an ultrasound or MRI as the initial screening imaging modality continues to be at the discretion of the surgeon and availability within each hospital system.

5. Laboratory evaluation

Routine laboratory workup for MoM arthroplasty surveillance includes a full blood count (FBC), serum C-reactive protein (CRP) level, erythrocyte sedimentation rate (ESR), and serum metal ion levels. Hip aspirate analysis can also be performed in situations where there is concern for a prosthetic joint infection.

While elevated serum ESR and CRP levels should raise concern for infection, caution should be exercised when interpreting levels. Elevated ESR and CRP levels have both been reported in cases of non-infected pseudotumour.[40] Serum metal ions, typically cobalt and chromium, should be routinely obtained in patients who are symptomatic, have radiographic changes, malpositioned components, or recalled implants.[3] Increased cobalt levels (compared to pre-operative levels) have been demonstrated in well-functioning MoM implants, with a peak between 6- and 12-months post-operatively.[41] Asymptomatic patients with well-functioning MoM hips can be expected to have serum cobalt and chromium levels of 2 parts per billion (ppb).

Although it is accepted that grossly elevated metal ion levels raise concern for ARMD, controversy exists in determining the optimal cut-off levels. Hart et al. initially defined a cobalt and chromium cut-off level of > 7 ppb[42] which was subsequently adopted by the MHRA, Health Canada, and the Hip Society algorithm for MoM arthroplasty surveillance.[13,43,44] However, there is concern that a cut-off of 7 ppb results in a high specificity but low sensitivity. In a separate study, Hart et al. determined a specificity of 89% and a sensitivity of 52% when the cut-off level was set at 7 ppb.[45] The authors subsequently recommended to lower the cut-off levels of cobalt and chromium to 4.97 ppb, with a resulting sensitivity of 63% and specificity of 86%.[45] There is also increasing evidence that an increased cobalt to chromium (Co/Cr) ratio can predict ARMD in patients with MOM THA, and in particular indicate taper corrosion.[46,47] However, the overall utility of metal ion levels is controversial in itself, with one systematic review and meta-analysis concluding they are not useful tests for determining ARMD in asymptomatic patients.[48] While increased cobalt and chromium in isolation may not reliable in detecting ARMD, it is a useful adjunct in the evaluation of a patient with a MoM arthroplasty.

Hip aspiration for cell count, differential, culture and sensitivities is useful in situations where there is clinical concern for a prosthetic joint infection. The sterile effusion associated with metallosis has been classically described as a watery, hazy, yellowish-grey fluid medium with a similar appearance to “dish-water fluid”.[3] Fibrinous debris from MoM reactions can falsely elevate automated cell count levels, and a manual cell differential count should be performed to minimise false positives.[3] Regardless, an increased cell count and elevated synovial neutrophil percentage (PMN%) should raise suspicion for infection.

6. Treatment algorithms

6.1. Asymptomatic patients

The treatment strategies for patients with MoM implants are different for asymptomatic and symptomatic patients (see Fig. 1).[38] Optimal follow-up and treatment for asymptomatic patients remains controversial. Measurement of serum ion levels should be measured routinely for asymptomatic patients with known risk factors for developing ARMD. These include malpositioned components (specifically an acetabular abduction angle $\geq 50^{\circ}$), radiographic changes suggestive of osteolysis or loosening, and patients with recalled implants. In the absence of these risk factors, annual follow-up with an Oxford Hip score assessment and plain radiographs is appropriate for asymptomatic patients.[38,43]

Asymptomatic patients with known risk factors require measurement of serum cobalt and chromium levels. The UK MHRA,[13] Health Canada[49] and the Hip Society[43] (Fig. 1) all recommend 7 ppb as a cut-off for serum cobalt and chromium levels, with other authors advocating for this to be dropped to 4.97 ppb.[45] The

Device implanted	**Hip resurfacing (no stem):** - female - male (femoral head diameter ≤48mm) - All DePuy ASR hip resurfacing devices **Stemmed total hip replacement (THR):** - femoral head diameter ≥36mm	**Hip resurfacing (no stem):** - male (femoral head diameter >48mm) **Stemmed total hip replacement (THR):** - femoral head diameter <36mm		
Patient and device group	**Symptomatic and asymptomatic**	**Symptomatic**	**Asymptomatic** • All stemmed THR • Resurfacing devices without 10A ODEP rating	Resurfacing devices with 10A ODEP rating (Table 2)[5,6,7]
Frequency of follow-up after primary operation date	Annually while the device remains implanted.	Annually while the device remains implanted.	Annually for the first five years, two yearly to ten and three yearly thereafter	First year, once at seven years and three yearly thereafter
Questionnaire	Oxford Hip score assessment	Oxford Hip score assessment	Oxford Hip score assessment	Oxford Hip score assessment
Imaging	• MARS MRI or ultrasound recommended if negative change in Oxford Hip Score is observed and/or elevated/rising blood metal levels.	• MARS MRI or ultrasound in all cases	• Plain radiographs • MARS MRI or ultrasound recommended if negative change in Oxford Hip Score is observed and/or elevated/rising blood metal levels.	• Plain radiographs • MARS MRI or ultrasound recommended if negative change in Oxford Hip Score is observed and/or elevated/rising blood metal levels.
Blood Metal Level Test [1,2,3]	All patients.	All patients.	All patients.	All patients.
Consider need for revision [4]	If imaging is abnormal and/or blood metal levels rising, and/or hip related clinical function / Oxford hip score deteriorating	If imaging is abnormal and/or blood metal levels rising, and/or hip related clinical function / Oxford Hip Score deteriorating	If imaging is abnormal and/or blood metal levels rising, and/or hip related clinical function / Oxford Hip Score deteriorating	If imaging is abnormal and/or blood metal levels rising, and/or hip related clinical function / Oxford Hip Score deteriorating

Fig. 1. Management recommendations for patients with metal-on-metal hip replacement implants.
Medicines and Healthcare Products Regulatory Agency. Management recommendations for patients with metal-on-metal hip replacement implants https://assets.publishing.service.gov.uk/media/5954ca1ded915d0baa00009b/MDA-2017-018_Final.pdf.[38]

European multidisciplinary consensus statement suggested a wide cut-off range of 2–7 ppb, acknowledging the controversies in defining a cut-off level.[50] Patients with low serum metal ion levels can be followed up with repeat plain radiographs and metal ion levels on an annual basis.[15] Asymptomatic patients with elevated cobalt and/or chromium levels should be investigated with advanced imaging. With no clear consensus on the best initial imaging test, the majority of treatment algorithms recommend

either ultrasound or MARS MRI as appropriate investigations to assess for adverse soft tissue lesions.[43] Patients with elevated serum metal ions and no evidence of fluid or mass on advanced imaging should be followed up closely every 3–6 months.[43]

Asymptomatic patients with evidence of ARMD on ultrasound or MRI remain a clinical challenge. It has been reported that soft tissue lesions will progress and become symptomatic in these patients.[8,16] There is evidence that early intervention prior to significant soft tissue destruction leads to improved post-operative outcomes following revision THA.[8] A detailed discussion with the patients is required, and revision surgery should be considered with increasing metal ion levels, interval radiographic changes, or onset of symptoms.[3] Patients who do not subsequently undergo revision THA should be followed up closely every 3–6 months.[3,43]

6.2. Symptomatic patients

Symptomatic patients require a comprehensive history and physical examination, serum metal ion levels, and advanced imaging with ultrasound and/or MARS MRI. Specific attention should be made to rule out other common causes of hip pain following arthroplasty. Patients with low metal ion levels and no evidence of fluid or mass on imaging can be closely monitored every 3–6 months with repeat ions levels and plain radiographs.

Patients with increased serum metal ion levels but no evidence of fluid or mass on imaging represent a moderate to high risk group.[3,43] Patients with low serum metal ion levels but evidence of fluid or mass on imaging also fall into this risk category.[3] Revision surgery should be considered in these patients with progressive symptoms, acetabular component abduction angle $\geq 50^{\circ}$, radiographic evidence of loosening or osteolysis, and poor implant track record.[3,43]

The highest risk group is represented by symptomatic patients with elevated serum cobalt and chromium in combination with presence of fluid or a mass on advanced imaging. These patients are best managed with prompt revision surgery.

7. Revision total hip replacement

Revision surgery for MoM arthroplasty requires a clear indication and careful review of the history, physical examination, imaging, and laboratory results. Common indications for revision THA following MoM arthroplasty include progressive symptoms, malpositioned components, pseudotumour, osteolysis, loosening, instability, and periprosthetic fracture. Initial outcomes following revision THA for ARMD were poor, with reported major complication rates of 38% including instability, deep infection, recurrence of ARMD, neurovascular injury, component loosening, and reoperation.[18] These early poor results led to the development of treatment algorithms and adoption of a lower threshold for revision surgery.[3,43]

Revision THA for MoM arthroplasty varies widely in complexity given the heterogenous nature of ARMD.[51] Surgical goals include excision of all metallosis within the soft tissues and implantation of well-positioned components to optimise stability. Formal intraoperative photos should be taken, and specimens should be sent for culture and histology.[3] Removed MoM implants should be sent for retrieval analysis.

In the setting of minimal soft tissue damage, well-positioned components can be retained if stable. Large pseudotumours with significant soft tissue necrosis and osteolysis typically require extensive debridement and reconstruction with revision components and possible augments. Pseudotumours that involve local neurovascular structures may require assistance from a vascular or plastics surgeon for safe exposure and debridement. It is important to recognise that MoM hip resurfacing and large-head MoM THA are different entities, with taper corrosion often the aetiology of ARMD in MoM THA. If the femoral component is retained, a taper adapter should be added to the trunnion to prevent further corrosion.[51] However, if significant macroscopic damage to the trunnion exists, femoral revision is necessary to prevent ongoing metal ion deposition. Patients should be revised to non-MoM bearing surfaces, with poor outcomes demonstrated when MoM bearing surfaces are used during revision.[52] It has been proposed that revision with ceramic-on-polyethylene bearing surfaces may minimise further metal wear; however, similar outcomes have been shown with metal-on-polyethylene bearing surfaces.[53] Current literature suggests that both are appropriate to use during revision.[53] In contrast, utilisation of ceramic-on-ceramic bearing surfaces during revision is associated with an 86% increased risk of re-revision.[51]

Extensive soft tissue damage to the hip capsule and abductor muscles should be anticipated. This can significantly affect inherent stability, and early studies have reported dislocation in 28% of patients undergoing for revision for ARMD.[18] Jennings et al. also reported a dislocation rate of 22% following revision THA with an isolated head and liner exchange only.[54] This may be related to ongoing metal ion release from corrosion of the damaged taper.[46] While isolated head and liner exchange may be appropriate in some patients, surgeons should be aware of the high risk of instability and critically evaluate component position and evidence of corrosion. A dual-mobility acetabular system or constrained liner may be necessary to obtain stability, and surgeons should have a low threshold to revise damaged or malpositioned components.[51]

An increased risk of post-operative infection has also been associated with revision THA for ARMD. The host response to bacteria may be influenced by metal ion-induced cytotoxicity and generation of a cell-mediated immune response.[55] Progressive soft tissue necrosis and the presence of a large effusion and pseudotumour may represent an ideal environment for infection, particularly from acute haematogenous spread.[55] In a retrospective single-institution review, Wyles et al. reported an 8.1% risk of re-operation for infection following revision THAs for MoM arthroplasty. Other described risk factors for infection include incomplete excision of necrotic tissue or metal debris, multiple operations, and retention of primary MoM components.[18,56]

Outcomes following revision THA for ARMD are historically poor compared to MoM arthroplasty revised for non-ARMD indications and conventional primary THA.[18,57] However, early studies generally described revision THA in the setting of extensive soft tissue necrosis and pseudotumour, which are associated with worse outcomes.[15] This has led to the adoption of structured surveillance programmes and a push towards early revision prior to extensive soft tissue damage.[8,15,57] It is likely early surgery has resulted in a decreased re-operation rate following revision. 5-year survival rates of 90% have been reported in ARMD revisions for MoM hip arthroplasty in the national joint registry in England and Wales.[53] In another recent retrospective review of the NJR data, MoM THAs revised for ARMD had half of the risk of re-revision compared to non-ARMD revisions, even when revision for infection was excluded.[58] Other factors that increased risk of re-revision for MoM arthroplasties revised for ARMD were high body mass index (BMI) at the time of revision surgery, modular component only revisions, use of MoM or ceramic-on-ceramic revision bearings, and acetabular bone grafting.[53] Most subsequent studies have reported excellent functional outcomes following revision.[51,52,59] A comparison of MoM THA revisions to first time metal-on-polyethylene THA revisions reported no difference in patient reported outcomes at 1-year post-operative.[60] A Medicare database review of isolated acetabular revision for MoM and metal-on-polyethylene THA also

reported no difference in complication rates at 2 years. These included dislocation, infection, and re-revision.[61] There is also growing evidence that ARMD revisions performed at high-volume centres have better outcomes and lower rates of complications and re-revision.[62,63]

Routine follow-up with plain radiography and measurement of metal ion levels is necessary following revision surgery for ARMD. Serum cobalt and chromium ion level typically decrease dramatically in the first 3 months post-revision surgery.[64] This drop is not as predictable in patients with pre-revision chromium levels >20 μg/L, and levels of >5 μg/L can be measured 1 year post-operative.[64] Regardless, measuring the trends in the metal ion levels may help identify cases of recurrent ARMD, and persistent elevation warrants investigation with ultrasound or MRI.

8. Conclusion

As the understanding of ARMD has evolved, MoM THA has become obsolete and MoM hip resurfacing has significantly decreased in popularity. However, a sizable population currently exist with a MoM arthroplasty in situ, and it is imperative these patients undergo routine surveillance including history, physical examination, and evaluation of metal ion levels. Ultrasound and MARS MRI both remain acceptable options to identify evidence of ARMD, with some authors advocating ultrasound as the initial investigation given its decreased cost and higher specificity. Outcomes following revision are dependent on the indication, with poor results associated with the presence of pseudotumour and abductor deficiency. Fortunately, the introduction of structured surveillance and early revision surgery prior to extensive soft tissue destruction has improved outcomes. Operative strategies for revision THA vary from exchange of modular components to extensive debridement and reconstruction with revision components. Surgeons should have a low threshold to revise damaged or malpositioned components to prevent further metal ion deposition. In addition, MoM bearing surfaces should be revised to ceramic-on-polyethylene or metal-on-polyethylene systems. While MoM THA are no longer implanted, there still is a role for hip resurfacing with the right indications and careful follow-up.

Contributor statement

Chang JS was responsible for manuscript preparation and submission. Haddad FS contributed to manuscript preparation and edited the paper.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare no competing interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcot.2019.09.021.

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