Until recently, metal-on-metal (MoM) hip implants were commonly used for joint replacement and resurfacing. MoM articulations offer several advantages over conventional metal-on-polyethylene bearings, including superior wear properties and the opportunity to use large diameter heads. These advantages led to the implantation of more than one and half million MoM hips worldwide. However, it has become apparent that these devices are prone to high rates of early failure [37]. The UK health regulator, the Medicines and Healthcare products Regulatory Agency (MHRA), now recommends monitoring of patients with these hips for life [27].

In 2010 the MHRA released a Medical Device Alert (MDA) regarding soft-tissue lesions associated with revision of MoM hip prostheses [26]. The soft-tissue necrosis caused by metal debris released from the MoM articulation may adversely affect the results of revision surgery. Early intervention of poorly performing implants was recommended to improve revision outcomes. These lesions are now well documented in the literature under various terms including pseudotumours [32]. These soft-tissue reactions, often given the umbrella term adverse reactions to metal debris (ARMRD) or adverse local tissue reaction (ALTR), are thought to be responsible for a large proportion of unexplained MoM hip failures. The mechanism of pseudotumour formation is currently unknown but an inflammatory/immunological hypersensitivity pathway in response to the release of cobalt (Co) and chromium (Cr) particles has been proposed [11].

Material loss from the implant-bearing surfaces is thought to be a source of metal debris. This may result in raised ion levels in the local tissues and or the systemic circulation. Some ions, such as Cr(VI), are known to have genotoxic/carcinogenic effects [30] so it was thought that metal implants may increase the risk of cancer. Evidence has subsequently shown that only non-carcinogenic Cr(III) ions are released [12]. A large population study using data from the National Joint Registry (NJR) looked at the incidence of various cancers in 40,576 patients with MoM hips and 248,995 patients with alternative bearing surfaces [36]. They found no evidence that MoM hips were associated with
an increased risk of cancer at 7 years post-implantation. Nonetheless, the term pseu-
dotumour is still used and continues to cause anxiety to patients.

**Current situation**

Orthopaedic surgeons face the challenge of predicting which implants will fail and when. This is a difficult task incorporating implant-, surgical- and patient-related factors. Current MHRA guidelines from 2012 recommend patients with MoM hips are monitored using a combination of clinical assessment, blood metal ion levels and cross-sectional imaging (ultrasound [USS], computed tomography [CT] or magnetic resonance imaging [MRI]).

**Blood metal ions**

The association between metal debris and soft-tissue reactions makes metal ions an obvious choice for non-invasive monitoring. Excessive release of wear particles has been linked with increased rates of failure [14]. Current MHRA guidelines recommend that blood metal ion levels of 7 parts per billion (ppb) of either cobalt or chromium warrant attention as a possible indicator of failure [25]. However this is an arbitrary threshold without scientific basis. The US Food and Drug Administration (FDA) Safety Communication regarding MoM hip implants, issued in January 2013, does not specify any specific ion levels to trigger revision or additional investigations.

**Imaging**

Traditional orthopaedic imaging modalities such as plain film radiography, CT and bone scintigraphy tend to focus on hardware positioning and bone quality. They are therefore of limited use for the evaluation of the soft-tissue lesions associated with MoM hips [19]. In light of this, alternative imaging modalities, such as MRI, have been suggested.

**MARS MRI**

MRI enables excellent overall appreciation of soft and hard tissues. However the presence of metal within the scanner leads to a susceptibility artefact being produced around the implant. This leads to signal loss and distortion which obscures the periprosthetic anatomy. Metal artefact reduction sequences (MARS) have been optimised to significantly reduce the periprosthetic artefact produced with conventional sequences. MARS MRI provides a sensitive modality for the detection of small or deep lesions as well as abductor muscle atrophy and tendinous avulsion. However, the residual artefact often obscures structures directly adjacent to the implant including effusions and tendinous attachments. Contrary to perceived concerns about implant heating, we have safely imaged over 1000 patients in a 1.5 T MRI scanner.

Current guidelines recommend the use of CT, USS or MARS MRI but do not state which is best ([Tab. 1, [27]). A European
Computed tomography vs. MARS MRI

CT and MARS MRI are multi-planar modalities from which the extent of pathology is readily appreciated. CT is useful in determining suboptimal component orientation aiding the identification of MoM patients at risk of failure due to elevated wear [14]. Moreover the utility of CT images at detecting bony changes has led to its emergence as the preferred modality for investigating periprosthetic osteolysis associated with hip arthroplasty [3, 34]. A previous cadaveric model, comparing MRI and CT for the detection of periprosthetic osteolysis suggested that MRI may in fact be the more sensitive modality [40]. However initial findings in vivo have shown MARS MRI is inferior to CT for detecting osteolysis associated with MOM arthroplasty, especially around the acetabular cup. With comparatively poor bone contrast, due to the low water content of cortical bone and the residual metallic artefact on MARS MRI images, evaluation of periprosthetic bone remains a challenge. The promise of new MRI sequences, such as multiacquisition variable-resonance image combination (MA-VRIC), which have been shown to improve periprosthetic bone visualisation [17], offer the potential of a single investigation with no ionising radiation exposure in the future.

Both CT and MARS MRI are capable of imaging soft-tissues in proximity to hip arthroplasty. MARS MRI is established as a highly sensitive tool for the detection of soft-tissue changes associated with MOM arthroplasty, namely pseudotumours and musculotendinous pathology [35]. However, in the absence of specific guidance from the MHRA or an evidence-based comparison there are centres in the UK that continue to use only CT as a means to investigate all MOM pathology, including soft-tissue changes. Preliminary findings from the first direct comparison of the diagnostic performance of 3DCT and MARS MRI strongly indicate that 3DCT is not a suitable substitute for MARS MRI in the follow-up of MOM patients. 3DCT has demonstrated suboptimal predictive values for pseudotumour and muscle atrophy detection. In these initial findings no classification system could be applied as the diagnostic characteristics were not discernible and only the largest pseudotumours were apparent on CT. It has been found that the inferior soft-tissue contrast and residual scatter of the images hindered the evalua-
**Leithema**

**Tab. 2** Pseudotumour classification system. Signal intensity of the pseudotumour contents is compared to the bladder signal on both T1- and T2-weighted image

<table>
<thead>
<tr>
<th>Pseudotumour Type</th>
<th>Wall</th>
<th>Contents</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Thin-walled</td>
<td>Fluid-like: hypointense on T1, hyperintense on T2</td>
<td>Flat, with walls mainly in apposition</td>
</tr>
<tr>
<td>2a</td>
<td>Thick-walled or irregular</td>
<td>Fluid-like: hypointense on T1, hyperintense on T2</td>
<td>Not flat, with &gt;50% of the walls not in apposition</td>
</tr>
<tr>
<td>2b</td>
<td>Thick-walled or irregular</td>
<td>Atypical fluid: hyperintense on T1, variable on T2</td>
<td>Any shape</td>
</tr>
<tr>
<td>3</td>
<td>Solid through-out</td>
<td>Mixed signal</td>
<td>Any shape</td>
</tr>
</tbody>
</table>

**Tab. 3** Muscle atrophy grading systems currently used to evaluate hip muscle atrophy

<table>
<thead>
<tr>
<th>Atrophy grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pfirmann et al. 2005 (29)</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Normal—no fat streaks present</td>
</tr>
<tr>
<td>1</td>
<td>Some fat streaks present</td>
</tr>
<tr>
<td>2</td>
<td>Fat evident, but less fat than muscle</td>
</tr>
<tr>
<td>3</td>
<td>Equal amounts of fat and muscle</td>
</tr>
<tr>
<td>4</td>
<td>More fat than muscle</td>
</tr>
<tr>
<td>Bal and Lowe 2008 [31]</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Normal</td>
</tr>
<tr>
<td>1</td>
<td>Not exceeding 30% decrease in muscle size</td>
</tr>
<tr>
<td>2</td>
<td>30–70% fatty change with accompanying decreased mass</td>
</tr>
<tr>
<td>3</td>
<td>Greater than 70% fatty change with 80% loss in muscle size</td>
</tr>
</tbody>
</table>

Muscle atrophy grading systems currently used to evaluate hip muscle atrophy. These systems aim to standardize the reporting and interpretation of the findings. However, all guidelines offer little advice as to the interpretation of the findings.

**Pseudotumours**

Research has focused on pseudotumours due to their novelty and unknown implications. Pseudotumours can have a variety of appearances ranging from small, fluid-filled lesions to large, solid masses (Fig. 1). To differentiate between the pseudotumours, they can be classified into four types based on the appearance of their wall, shape and contents on MARS MRI ([15], Tab. 2). This classification system aims to standardize the reporting and may help predict clinical outcomes. Hauptfleisch et al. [16] reviewed 33 patients with pseudotumours identified on MRI and found thin walled (<3 mm) cystic pseudotumours were associated with the least severe symptoms, whereas predominantly solid pseudotumours were associated with the most severe symptoms (p=0.042) and the highest rates of revision (90.9%). However the significance of type 2 pseudotumours with thick or irregular walls, is less certain. A comparison of 30 patients with painful MoM hips with 28 patients with well-functioning MoM hips found the prevalence of pseudotumours to be high and roughly equal in both groups [15]. These findings have called into question the value of using MARS MRI [18].

**Ultrason vs. MARS MRI**

Soft-tissue imaging using either MARS MRI or USS has been recommended to evaluate the periprosthetic soft-tissues in patients with MoM prostheses [27]. Both MARS MRI and USS can be used to produce detailed images of the periprosthetic tissues. Although the choice of modality has been left at the discretion of the surgeon, there is an increasing preference towards the use of MARS MRI.

MRI images enable contralateral comparison of structures, which is particularly useful during abductor muscle atrophy assessment. Serial images can be compared over time and can be shared with specialist institutions to provide expert opinion during unequivocal cases. In addition, MARS MRI can be used to detect pathology unrelated to the hip, such as malignancy, and is useful during preoperative planning of revision surgery.

USS can also produce detailed images of the periprosthetic soft-tissues, distinguishing between solid or cystic composition of pseudotumours. Without the same problem of metal artefact, USS is able to image the structures directly adjacent to the prosthesis making it an excellent modality for the detection of joint effusion and tendinous pathology. It has been suggested that USS can be used during initial screening for pseudotumours. However, USS is operator dependant and requires an experienced musculoskeletal radiologist. In addition, as resolution diminishes with depth, small or posterior lesions may be missed. A systematic USS examination can be useful during evaluation of patients where MARS MRI is poorly tolerated, contraindicated or unavailable (Siddiqui Clinical Radiology).

**Interpretation of MARS MRI**

MARS MRI is recognised as a useful investigation for MoM implants and its use has been recommended in multiple healthcare regulatory guidelines. However all guidelines offer little advice as to the interpretation of the findings.

**Muscle atrophy**

MARS MRI can detect a number of pathologies, in addition to pseudotumours, that may be of clinical importance. Involvement and destruction of the hip muscles may be a more significant predictor of outcome than the pseudotumour itself. The hip abductor muscles are an important pair of muscles located lateral to the hip joint and are responsible for stabilizing the pelvis when the contralateral leg is raised [38]. The tonal contraction of the abductors also ensures the head of the femur is held in the acetabular cup of the pelvis [2]. Therefore abductor muscle deficiency can cause pain, abnormal gait and...
predispose patients to joint instability and dislocation.

Traditionally, post-operative muscle damage has been linked with surgical exposure, either by direct or neurological damage. A lateral approach involves detachment or dissection of the hip abductors which may cause permanent damage to the muscles. However, surgical insult is not the only cause of muscle atrophy. Muscle damage and tendon avulsion have also been recorded in association with metal implants [5]. Metal debris has the potential to cause an inflammatory response capable of destroying tendon and or muscle tissue. Muscle deficiency is likely to be a major cause of poor outcomes following revision of patients with MoM implants [8, 29]. A study of 174 patients (192 MoM hips) found the only MRI findings that were consistently associated with symptoms were abductor tendon defects and bone marrow oedema [4].

At our institution we routinely evaluate muscle atrophy in patients with MoM hips that have had MARS MRI. The glutei, short external rotators and iliopsoas muscle are graded. In addition, gluteus medius is assessed as three separate parts – anterior, middle and posterior – to locate any pathology more precisely. There are currently two systems in current use for grading muscle atrophy (Tab. 3). The Pfirrmann system [33] uses fatty infiltration to rate the severity of muscle atrophy, ranging from no fatty infiltration (grade 0) to more fat than muscle (grade 4; Fig. 2). This is founded on a system used to assess rotator cuff injuries of the shoulder [7]. The Bal and Lowe system [1] grades muscle atrophy on a scale of 0–3 based on fatty infiltration and muscle bulk via comparison with the contralateral side. In our experience, Bal and Lowe is more intuitive but does have the disadvantage that bilateral patients are harder to evaluate.

We are currently investigating the influence of muscle atrophy on hip function in MoM patients. Preliminary results suggest that a lateral surgical approach used at implantation has a detrimental effect on abductor muscle atrophy. This finding is in accordance with published literature that has reported higher levels of abductor dysfunction after a lateral approach [24]. Therefore abductor atrophy following a posterior approach, not involving the abductor muscles, may be of greater concern. We suggest that surgical approach should be considered along with other clinical information during the interpretation of MRI findings.

There also appears to be a poor correlation between muscle atrophy and hip function. This is in contrast to the findings of Pfirrmann et al. [33] when it was found muscle atrophy and tendon defects were significantly higher in symptomatic patients. These initial results suggest that muscle atrophy can be relatively well compensated for. Muscle atrophy may therefore progress ‘silently’ without eliciting symptoms until an advanced stage (Fig. 3). Abductor muscle damage is difficult to treat, often with unsatisfactory results [31]. Animal models and studies of rotator cuff injuries have also shown that muscle atrophy is largely irreversible [39]. Various strategies can be employed to reduce the chance of dislocation such as using constrained cup liners, modular cups and large diameter heads but again these may not be sufficient compensation for the lack of musculature (Fig. 4). Early detection and intervention is therefore advisable, especially if the implant itself may be a cause of the damage. MARS MRI has the ability to identify muscle atrophy in well-functioning patients, before clinical deterioration and at a salvageable stage.
Fig. 3 A T1-weighted image of a 56-year-old woman. Scan shows severe wasting and fatty infiltration of gluteus medius and minimus (Pfirrmann grade 3, Bal and Lowe grade 3) on the instrumented right side. At the time the patient reported a moderately high Oxford Hip Score of 30 out of maximum of 48.

Fig. 4 A This plain film shows a dislocated large diameter head. This indicates severe muscle insufficiency. At revision there was 80% destruction of gluteus medius.

Future research

Studies that have included asymptomatic patients have demonstrated there is often poor agreement between MRI findings and clinical presentation. However these studies have been limited by a lack of longitudinal follow-up. The natural history of pseudotumours is not known so asymptomatic patients showing soft-tissue pathology on MARS MRI may go on to develop symptoms.

There is also a lack of published literature comparing MARS MRI findings in non-MoM hips. There have been reports of pseudotumours associated with conventional, metal-on-polyethylene (PoM), hip replacements [9, 20, 21, 23, 41, 42] but there have been few direct comparisons with MoM hips. Without this it is hard to know how much of the observed pathology is directly attributable to the MoM prosthesis. Mistry et al. [28] compared MRI findings of 10 PoM and 12 MoM asymptomatic hips with normal radiographs and found a higher incidence of soft-tissue changes in the MoM although this was not significant. Larger studies comparing PoM and ceramic bearings should be conducted.

Conclusion

MARS MRI is established as a valuable tool for the assessment of patients with MoM implants. Excellent soft-tissue contrast and the ability to share and compare images offer advantages over alternative imaging options. Current research aims to help clinicians interpret MARS MRI findings and relate them to clinical outcomes. This will help clinicians with decision-making regarding management of borderline patients. Future research should include longitudinal studies to delineate the natural history of soft-tissue damage and this should be compared with other bearing surfaces as a control. Pre-revision MARS MRI findings also need to be correlated with post-revision outcomes. We advocate the use of MARS MRI for patient monitoring and as an aid to decision-making in conjunction with other clinical information.

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Conflict of interest. On behalf of all authors, the corresponding author states the following: AH works as a consultant to Depuy for the clinical assessment of patients with MoM hips. KS is a committee member of Johnson and Johnson.

References


