MRI of hip arthroplasty

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Learning objectives

1) To describe how to establish a protocol for a MRI study of hip arthroplasty.

2) To show limitations and usefulness of MRI in assessing complications of hip arthroplasty.

3) To show the MR imaging findings linked to complications of hip arthroplasty.
Background

Hip arthroplasty procedures are increasing and are expected to increase in the forthcoming decades. What is more, it is being increasingly performed at younger ages.

Long-term success of a hip replacement is mainly dependent on the wear characteristics of the bearing surfaces used. Eventually all arthroplasty procedures will fail over time primarily due to the association between wear debris, particularly polyethylene particles, and aseptic loosening.

Therefore research on this area was performed in the past to introduce bearing surfaces with lower wear in order to reduce future revision burden. In this way, metal on metal (MOM) bearing surfaces were introduced due to their advantage of low wear and were initially used in young and active patients.

Currently, two types of joint replacements with MOM bearing surfaces are available:

- MOM hip resurfacing: the femoral neck is preserved
- MOM total hip replacement

Clinical concerns linked to MOM hips include: 1) risk of fracture neck with hip resurfacing. 2) abnormal soft tissue reaction to wear debris. 3) Infection. 4) Tendinopathies and gluteal tendon insufficiency.

- The issue of risk of femoral neck fracture is mainly associated to the surgical technique and the incidence is far below 1%.

- However, the incidence of abnormal soft tissue reactions are on the increase. Abnormal soft tissue reactions linked to wear debris cause a spectrum of damage in the hip joint and surrounding soft tissues ranging from joint fluid and synovitis, bone destruction and osteolysis and soft tissue collections / pseudotumours sometimes with extensive soft tissue destruction.

- The incidence of infection is also less than 1% following hip arthroplasty. X-rays are often normal and findings on nuclear scintigraphy may be non-specific.

Therefore an alternative or complementary imaging technique to assess potential complications of hip arthroplasty procedures is needed. In this way MRI has recently emerged in the clinical setting as a novel imaging technique to assess complications associated with hip arthroplasty.
Imaging findings OR Procedure Details

In order to perform a MR study of the hip arthroplasty, it is necessary to know the factors that may affect the susceptibility artefacts caused by the metallic hardware of the arthroplasty and to implement MR sequences with lower sensibility to susceptibility artefacts.

Factors affecting the susceptibility artefact Fig. 1 on page 9

1) Relative ferromagnetism of the prosthesis
2) Orientation of the hardware relative to magnetic field Bo
3) Geometry of the prostheses

Implementation of MR sequences to reduce metallic artefacts: technical factors and pulse sequence parameters Fig. 2 on page 9, Fig. 3 on page 9

1) Lower field strength
2) Increased BW
3) Decreased voxel size
4) Increase number of excitation (NEX)
5) Orientate the frequency-encoding direction along the longitudinal axis of the prostheses
6) Use FSE sequences instead of SE or GRE sequences
7) Use STIR sequences instead of fat-saturated intermediate or T2-weighted sequences.

Complications associated to hip arthroplasty procedures

Wear-Induced Synovitis

Well-functioning metal on metal hip arthroplasties need fluid lubrication. Under edge-loading conditions, the lubrication fails and this is usually associated with massive wear.
Eventually all components of a hip arthroplasty undergo wear leading to shedding of debris and particle disease.

Debris from the polyethylene component induce the highest inflammatory response in the setting of particle disease. Particle disease starts as a synovial process and may progress over time to osteolysis and loosening. However, wear-induced synovitis is a slowly progressing process.

On MRI, polyethylene wear-induced synovitis appear as expansion of the pseudocapsule by debris or fluid in the joint Fig. 4 on page 10, Fig. 5 on page 11. When the intraarticular pressures increase, decompression of debris and fluid into the iliopsoas and sub-iliacus bursae can be seen.

**Membrane formation and Periprosthetic Osteolysis**

Very large numbers of very small cobalt-chrome wear induce a macrophage-mediated immune response upregulating osteoclasts and downregulating osteoblasts resulting in periprosthetic bone resorption, membrane formation and osteolysis. When osteolysis is extensive, implant loosening develops.

Osteolysis can be detected by imaging techniques. However, correlation between osteolysis and clinical loosening is not so clear, as many patients remain asymptomatic in spite of osteolysis.

Although classically the diagnosis of osteolysis has been performed by the use of serial X-rays, it is well-known that radiographs underestimate the extent of bone resorption. MRI has recently emerged as a more sensitive imaging technique to detect the changes of periprosthetic osteolysis at an earlier stage than X-rays and CT.

On MRI, periprosthetic membrane formation appears as a smooth intermediate signal intensity layer along the interface between the implant and the adjacent normal bone marrow Fig. 6 on page 12. Osteolysis appears as well-defined more rounded intraosseous lesions with intermediate and low signal components Fig. 7 on page 13.

**Adverse Local Soft Tissue Reactions and Pseudotumours**

The terms "adverse local soft tissue reactions", "pseudotumour" and "adverse reactions to metal debris" have been used synonymously.

These terms imply various soft tissue reactions to metal debris, corrosion products and metal ions. They can occur through hypersensitivity reactions to metal products in the setting of low wear (predominantly hypersensitivity-linked reactions) and through non-
hypersensitivity reactions in the setting of high wear (predominantly high wear-linked reactions or metallosis).

ALVAL (aseptic lymphocytic vasculitis associated lesion) is the histologic appearance of hypersensitivity reactions to metal. It is characterized by the presence of lymphocites, histiocytes, intracytoplasmic wear debris and necrosis.

On MRI hypersensitivity-linked reactions appear as periprosthetic soft tissue collections filled with synovial fluid and solid synovial debris. Sometimes the communication of this soft tissue collection with the joint is seen through the dehiscence of the pseudocapsule. Pseudocapsular dehiscence is most commonly seen in the lateral/posterolateral aspect of the joint allowing for decompression in the greater peritrochanteric area or into the greater trochanteric bursa Fig. 8 on page 14, Fig. 9 on page 15. When this peritrochanteric fluid collections come in contact with the hip abductor tendons there is an increased risk of tendon tear and abductor tendon insufficiency.

On the other hand, non-hypersensitivity-linked reactions or metallosis appear on MRI as a confluent intra-articular and intrasoseous low signal intensity mass with a lack of soft tissue disruption Fig. 10 on page 16.

**Infection**

Infection is an uncommon complication following hip arthroplasty procedures with a rate lower than 1%. X-rays are usually normal and serological tests such as erythrocytre sedimentation rate (ESR) and C-reactive protein have low specificity. Periosteal reaction is also low specific as it can be related to mechanical stress reaction especially in the setting of underlying aseptic loosening. The findings on nuclear scintygraphy scans performed with Technectium 99m-methylene diphosphonate are also nonspecific although high diagnostic accuracy has been reported with combined white blood cell and bone marrow scintigraphy.

MRI is helpful for the diagnosis of infection by depicting the findings associated to extracapsular spread of the infection such as soft tissue extracapsular oedema, abscesses and draining sinus Fig. 11 on page 17, Fig. 12 on page 18. Bone destruction with osteomyelitis and bone sinus tract can also be found.

A hyperintense lamellated appearance of the synovium has been reported as well with a high positive predictive value. However, image-guided joint aspiration is still required for a definitive diagnosis.

**Heterotopic ossification**
Heterotopic ossification consists of formation of lamellar bone with trabeculae in nonosseous tissues Fig. 13 on page 19. It is usually diagnosed with x-Rays or CT. Classic Brooker’s classification in four types/classes is traditionally followed.

Development of symptoms related to heterotopic ossification is uncommon after hip arthroplasty procedures. It is usually associated to impingement on adjacent nerves or tendons (abductor or iliopsoas tendons) or due to limited range of motion of the hip joint especially if ankylosing heterotopic ossification between periacetabular bone and femur has occurred Fig. 14 on page 20.

MRI can demonstrate the extent of the ossification process, the impingement on adjacent soft tissues and can be helpful in planning subsequent surgery.

Mature heterotopic ossification appears with fatty bone marrow signal intensity with a thin hypointense cortex or cortical inclusions. On the other hand, immature heterotopic bone appears isointense to muscle on T1 and hyperintense on STIR images. Following gadolinium contrast injection, peripheral rim enhancement may appear in immature heterotopic bone and it can be easily mistaken for infection.

**Tendinopathy**

Degeneration and tears of the hip abductor tendons are a common cause of pain after hip arthroplasty. Involvement of the tendons may be due to primary tendinopathy / partial to complete tears or secondary to impingement associated to pseudotumours, heterotopic ossification or less likely adjacent osteolysis.

Chronic tears of the abductor tendons mat appear as "scar-in continuity" up to the attachment in the greater trochanter. The gluteus medius and minimus tendons may also be scarred one to another or appear attached to the hip pseudocapsule or to the adjacent iliotibial band or vastus lateralis tendon Fig. 15 on page 21.

Fatty atrophy of the anterior aspect of the gluteus minimus muscle is a common finding in asymptomatic patients while involvement of the posterior aspect of the gluteus minimus and gluteus medius muscles are more likely to be clinically relevant Fig. 15 on page 21. Differential diagnosis between muscle atrophy due to a chronic tendinous tear and muscle atrophy due to chronic denervation after damage of the superior gluteal nerve is important to be made in limping patients after hip arthroplasty.

Iliopsoas tendon degeneration and tears are also a potential complication of hip arthroplasty. Iliopsoas tendinosis most commonly results from primary degeneration. Isolated iliopsoas bursitis may also appear Fig. 16 on page 20. Malposition of implants, cements or aberrant placement of fixation screws may also impinge on tendon and bursae.
**Other complications**

Other complications such as pelvic insufficiency fractures and non-displaced periprosthetic fractures can also be a source of pain in these patients. Periprosthetic fractures are usually detected by x-rays although occasionally MRI can be useful in detecting occult non-displaced periprosthetic fractures.

Nerve damage is an uncommon event occurring in 1-2% of hip arthroplasties. The sciatic nerve is most commonly involved. Superior gluteal nerve, femoral nerve, obturator nerve and lateral femoral cutaneous nerve are less commonly injured. The nerve can be damaged at the time of surgery by transection, ischemia or stretching or can be impinged by postoperative haematoma, pseudotumours, heterotopic ossification, malpositioned or displaced arthroplasty components Fig. 14 on page 20.

**MR protocol for hip arthroplasty**

Although different protocols can be applied for the proper evaluation of complications associated with hip arthroplasty, we usually perform modified intermediate fast spin-echo sequences in the coronal, sagittal and axial planes along with low or intermediate echo-time fast STIR sequences. T1 weighted sequences can also be used to depict acetabular areas of osteolysis more conspicuously. A proposed protocol is provided Fig. 17 on page 24.

3 Tesla magnets are not favoured to perform MRI studies of hip arthroplasty due to their increase susceptibility to metallic artefacts and distortions Fig. 18 on page 22. Some technical tips to reduce metallic artefacts may allow to identify selected complications associated to hip arthroplasties especially at the level of the femoral stem Fig. 19 on page 23. However, the use of 3 Tesla should be avoided whenever possible and it is recommended to perform MRI studies of hip arthroplasties on 1.5 Tesla magnets.

Dedicated metal artefact reduction techniques such as MAVRIC (multi-acquisiton variable resonance image combination) and SEMAC (slice encoding for metal artefact correction) have recently been introduced in the clinical setting. These new techiques reduce substantially metal artifacts and therefore can be used as alternative sequences to classic fast spin sequences.

Research in new biomaterials and design of hip joint replacement components along with further development of metal artefact reduction MRI sequences will allow to perform totally free-of-metal artefacts MRI studies in the foreseeable future.
### Fig. 1: Factors affecting the susceptibility artefact

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<table>
<thead>
<tr>
<th></th>
<th>Reduced artifact</th>
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<tr>
<td><strong>Relative ferromagnetism of the prostheses</strong></td>
<td>Titanium or oxidized zirconium</td>
<td>Cobalt-chromium</td>
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<td><strong>Orientation of the hardware relative to the main magnetic field (Bo)</strong></td>
<td>Paralel to B0 (head-to-toe): stem of femoral component</td>
<td>Unparalelled to B0 (head-to-toe): acetabular component</td>
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<tr>
<td><strong>Geometry of the prosthesis</strong></td>
<td>Linear components of the prostheses</td>
<td>Spherical or rounded components</td>
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### Fig. 2: Technical parameters and susceptibility

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<tr>
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<tr>
<td><strong>Main magnetic field (Bo)</strong></td>
<td>&lt; Bo Use 1.5 T or less</td>
<td>&gt; Bo 3 T increases artefacts x 2</td>
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<tr>
<td><strong>Spin-echo and GRE sequences</strong></td>
<td>Fast-SE sequences</td>
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<td><strong>Fat suppression</strong></td>
<td>Fast- STIR sequence</td>
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<td></td>
<td>(= increase resolution)</td>
<td>(= decrease resolution)</td>
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<td></td>
<td>Better 3D than 2D</td>
<td></td>
</tr>
<tr>
<td><strong>Bandwith (BW)</strong></td>
<td>&gt; BW</td>
<td>&lt; BW</td>
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Fig. 4: Wear-induced synovitis. Axial FSE intermediate and STIR sequences. Expansion of the pseudocapsule (yellow arrows) is seen in the anterior recess of the joint with evidence of mildly heterogeneous signal by debris and fluid in the joint (blue arrows).

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Fig. 5: Wear-induced synovitis. Coronal, axial and sagittal FSE intermediate sequences. Prominent low signal content by debris is seen in the joint (blue arrows) with expansion of the pseudocapsule (white arrow).

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**Fig. 6:** Membrane formation. Coronal FSE intermediate sequence. A smooth intermediate signal intensity layer is seen along the femoral stem component at the bone interface (blue arrows). Membrane formation can precede or be associated with loosening.

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Fig. 7: Osteolysis. Coronal, axial and sagittal FSE intermediate sequences and coronal STIR sequence. A bulky geographic intraosseous lesion with heterogeneous signal is seen in the posterior wall of the acetabulum with bony expansion (blue arrows). Smaller areas of osteolysis are also seen in the anterior wall (blue arrows).

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Fig. 8: Adverse local soft tissue reaction/ pseudotumour. Coronal T1, coronal and axial STIR sequences. A periprosthetic soft tissue collection filled with synovial fluid and mild synovial debris (blue arrow) is seen communicating with the joint through a dehiscence of the lateral pseudocapsule (white arrow). Some debris is also seen in the joint (blue arrow).

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Fig. 9: Adverse local soft tissue reaction/ pseudotumour. Coronal and axial intermediate FSE sequences. A periprosthetic soft tissue collection filled with synovial fluid and synovial debris (blue arrow) is seen communicating with the joint through a dehiscence of the lateral pseudocapsule (white arrow).

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**Fig. 10:** Metallosis. Axial intermediate FSE sequences and insets. Confluent low signal intensity mass (blue arrows) in the lower anterior aspect of the hip joint with no dehiscence of the pseudocapsule.

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**Fig. 11:** Infection. Coronal and sagittal intermediate FSE and coronal STIR sequences. There is evidence of thickening and signal increase of the pseudocapsule with adjacent ill-defined soft tissue oedema (yellow arrows) along with bone marrow oedema in the acetabular and femoral components (red asterisks) and a small fluid collection consistent with a small soft tissue abscess (blue arrows).

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**Fig. 12:** Infection (same patient). Axial STIR and substracted T1 GRE weighted images after intravenous contrast injection sequences. There is evidence of ill-defined soft tissue oedema pattern surrounding the hip joint with contrast uptake (yellow arrows) along with small foci of bone marrow oedema (red asterisks) and a small rim-enhancing soft tissue abscess (blue arrows).

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Fig. 13: Heterotopic ossification. Coronal and axial intermediate FSE sequences. Mature osteochondroma-like heterotopic ossification adjacent to the lesser trochanter appears with fatty bone marrow signal intensity with a thin hypointense cortex. Note the small metallic artefacts in the medial aspect of the heterotopic ossification.

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Fig. 14: Limited range of motion due to ankylosing heterotopic ossification between periacetabular bone and femur. Coronal and sagittal intermediate FSE. Prominent heterotopic ossification is seen in the posterior aspect of the proximal femur (blue arrows) which extends in continuity through the level of the joint up to the periacetabular bone (yellow arrows). Secondary impingement on the sciatic nerve is also identified with mild fading of the nerve fascicles at this point (circle and red arrow).

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**Fig. 16:** Iliopsoas bursitis. Coronal, sagittal and axial FSE intermediate sequences and axial STIR sequence. Focal fluid distention of the subiliacus bursa is seen (blue arrows). Iliopsoas bursitis can appear as a primary complication or related to decompression of intraarticular wear-induced synovitis.

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**Fig. 15:** Detachment of the gluteus minimus and anterior aspect of the gluteus medius due to pseudotumour. Axial and sagittal intermediate FSE sequences. A peritrochanteric fluid collection consistent with a pseudotumor is seen anterior to the femoral neck component of the arthroplasty (green asterisks). The gluteus minimus tendon (yellow arrow) and the anterior aspect of the gluteus medius tendon (blue arrow) appear irregular above the pseudotumour with moderate fatty infiltration of the muscle bellies (red asterisks). At the level of the pseudotumour both tendinous structures become confluent at the anterior wall of the pseudotumour. Distally both tendons appear in continuity to the vastus lateralis tendon (combined yellow and blue arrows).

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**Fig. 18:** 3T susceptibility. Coronal and axial T1 GRE survey sequences and coronal T1 sequences. Prominent metallic artefacts are seen when MR studies of hip arthroplasties are performed in a 3 Tesla magnet and no metal artefact reduction techniques are performed. Therefore, performing a clinically useful MRI study of the hip arthroplasty can be impaired.

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**Fig. 19:** 3T susceptibility. Axial and sagittal FSE intermediate and STIR sequences performed on a 3T magnet. After using some technical tips to reduce metallic artefacts and distortion, the artefacts related to hardware have decreased allowing for the evaluation of osteolysis in the femoral stem in this patient with symptoms of loosening. Findings were confirmed at surgery. However, although reduced, the metallic artefacts impaired the proper assessment of the articular joint. Therefore, it is recommended to perform MRI studies of hip arthroplasties on 1.5 Tesla magnets.

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<td>3-4 / 0</td>
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**Fig. 17:** Proposed MRI protocol

Conclusion

MRI allows to assess most complications associated to hip arthroplasty.

Knowledge of basic technical tips allows to reduce the susceptibility artefacts and distortions caused by metallic implants.

Development of novel sequences to further reduce metal-induced artefacts will allow a full and detailed assessment of complications of hip arthroplasty.
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