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Technical Report

Cross-sectional imaging of the metal-on-metal hip prosthesis: The London ultrasound protocol

I.A. Siddiqui [a], S.A. Sabah [a], K. Satchithananda [b], A.K. Lim [b], J. Henckel [a], J.A. Skinner [a], A.J. Hart [a,*]

[a] *Institute of Orthopaedic and Musculoskeletal Science, University College London, The Royal National Orthopaedic Hospital, London, UK*
[b] *Department of Radiology, Imperial College Healthcare NHS Trust, Imperial College London, Charing Cross Hospital, London, UK*

Introduction

Approximately 1.5 million patients worldwide have had metal-on-metal (MOM) arthroplasties implanted since 1996.[1] Unfortunately, they have high failure rates due to adverse tissue reactions in the periprosthetic tissues.[2,3] Ultrasound can detect these problems[4–6] and, therefore, has been recommended by health regulatory guidelines[7] on the clinical management of MOM hips.

Solid or cystic periprosthetic soft-tissue lesions, termed pseudotumours, and musculotendinous damage are commonly found around MOM hip implants. They are often associated with pain, loss of function, and ultimately in a higher incidence of revision surgery.[8] Cross-sectional imaging is useful to determine the aetiology of symptoms,[9] assess the extent of the lesion, and inform the decision to revise.[10]

Metal artefact reduction sequence (MARS) magnetic resonance imaging (MRI) is a sensitive tool for detection of pseudotumours and muscle atrophy. However, even with optimized imaging protocols, the interface immediately adjacent to the prosthesis can be obscured by artefact. It is a recognized limitation that small pseudotumours or joint effusions in this area may be missed at MARS MRI; however, the frequency of this and its clinical significance has not been well described in the literature.[8,11]

Unlike MRI, ultrasound does not cause metal artefact and may prove a useful alternative in patients where MARS MRI is poorly tolerated, contraindicated, or unavailable. Ultrasound is an established technique for detection of pseudotumours, tendinous abnormality, joint effusions, extra-articular fluid collections,[12] and can be used to assess muscle atrophy.[13] However, a systematic methodology for obtaining optimal results and an imaging spectrum for reference have not been published.

The authors present a systematic method using ultrasound to examine the periprosthetic tissues of patients with a MOM hip arthroplasty and provide reference imaging of the typical pathological and normal findings.

Materials and methods

Ultrasound examinations were performed individually by two consultant musculoskeletal (MSK) radiologists. The Toshiba Aplio A500 Ultrasound System (Toshiba Medical Systems, Zoetermeer, The Netherlands) was used with an 18 or 9 MHz linear transducer, in both the longitudinal and transverse planes, and where appropriate, the highest possible frequency was applied to provide adequate penetration. Lower frequencies were used depending on patient habitus, including a convex transducer (2–5 MHz), to improve penetration during posterior imaging.

Patients

Ethical approval was granted by the local ethics committee (Riverside Ethics Committee; COREC 09/H0711/3) and informed consent was obtained from all participating patients.

* Guarantor and correspondent: A.J. Hart, Institute of Orthopaedic and Musculoskeletal Science, University College London, The Royal National Orthopaedic Hospital, Brockley Hill, Stanmore, London HA7 4LP, UK. Tel.: +44 (0) 20 8954 2300.
E-mail address: imran.a.siddiqui@gmail.com (I.A. Siddiqui).

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Table 1
Classification of pseudotumours and muscle atrophy using metal artefact reduction sequence (MARS) magnetic resonance imaging (MRI) and ultrasound.

	MARS MRI		Ultrasound	
Pseudotumours[a]	Imperial type I	Flat, thin-walled (≤2 mm); fluid-like content	Imperial Type 1	Cystic lesion: internal fluid echo-texture; flat, thin-walled
	Imperial type IIa	Thick-walled (>2 mm); fluid-like content	Imperial Type 2	Cystic lesion: internal fluid echo-texture; atypical fluid; irregular thick-walled
	Imperial type IIb	Thick-walled (>2 mm); atypical fluid		
	Imperial type III	Solid	Imperial Type 3	Solid lesion: complex solid echo-texture
Muscle atrophy[b]	Grade 0	No change	Grade 0	No change
	Grade 1	≤30% reduction in muscle size	Grade 1	<30% size reduction or with some fatty replacement
	Grade 2	30–70% fatty change and reduction in size	Grade 2	30–70% size reduction with fatty replacement
	Grade 3	>70% fatty change with 80% reduction in size	Grade 3	>70% size reduction with marked fatty replacement

The following system is currently used to classify pseudotumours and muscle atrophy on MARS MRI. A similar grading system was developed for ultrasound classification.
[a] MARS MRI pseudotumour classification from reference 11.
[b] MRI muscle atrophy classification from reference 17.

Ultrasound was performed on patients according to the Medicines and Healthcare products Regulatory Agency (MHRA) guidance (MDA/2012/008),[9] for patients with a: symptomatic MOM hip (Oxford Hip Score ≤41/48)[14]; DePuy ASR MOM hip (resurfacing or stemmed replacement); or large femoral head diameter (≥36 mm) stemmed MOM components. Those patients with a contralateral hip prosthesis were excluded.

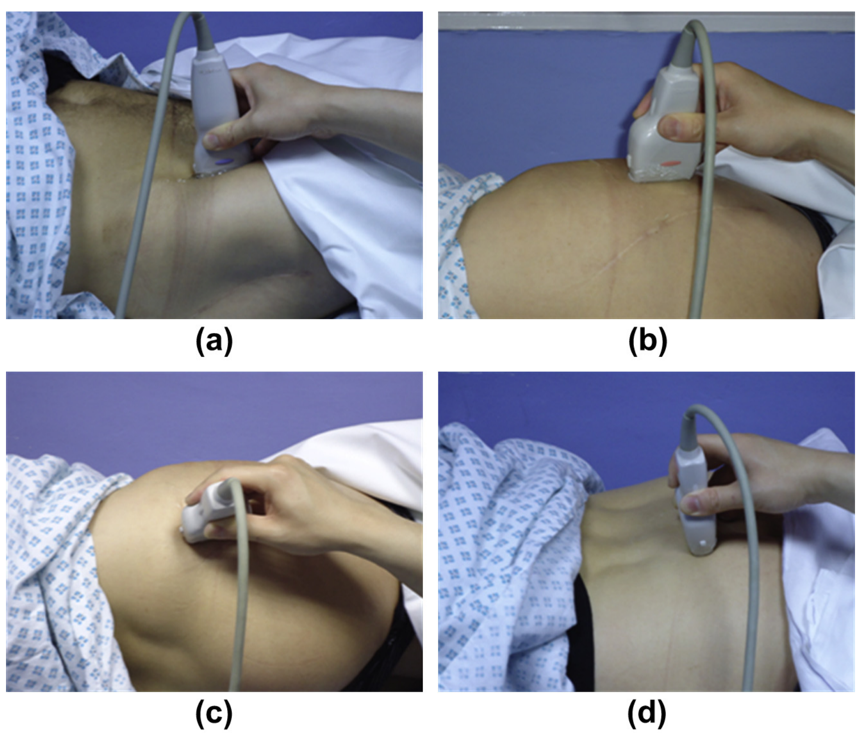

Figure 1 Pictorial ultrasound examination of the metal-on-metal hip (cranial aspect to left of the images). (a) Anterior examination of the right hip with the patient in the supine position: a sagittal plane parallel to the long axis of the femoral shaft and oblique to the femoral neck is used to evaluate the anterior synovial recess for an effusion. Scans in the longitudinal and transverse planes are also used to examine the iliopsoas muscle, tendon, and bursa. (b) Lateral examination of the right greater trochanter with the patient in the lateral decubitus position: longitudinal and axial scans of the greater trochanter are used to examine the trochanteric bursa and tendinous attachment of the gluteus medius and minimus muscles. (c) Lateral examination of gluteus medius and minimus muscles with the patient in the lateral decubitus position: longitudinal and axial scans are used to examine atrophy of the gluteus medius and minimus muscles. The midpoint position of the muscles is used to record diameter. (d) Posterior examination of the left hip with the patient in prone position: axial scans are used to examine the gluteus maximus muscle for soft-tissue lesions. The posterior joint can be imaged by scanning the posterior aspect of the greater trochanter. The surrounding soft tissues are fully visualized during each scan to identify the presence of pseudotumours. Lower frequency transducers may be used to achieve adequate penetration.

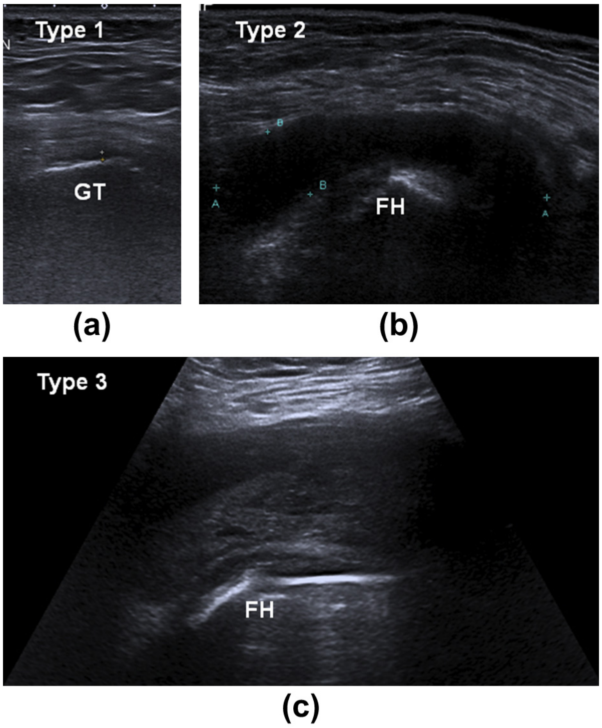

Figure 2 Ultrasound classification of pseudotumours (cranial aspect to left of the images). Longitudinal ultrasound images showing the different classifications of pseudotumours: (a) a type 1 lesion; a lateral image showing the trochanteric bursa with a small hypoechoic fluid collection; (b) a type 2 lesion; an anterior image showing a large anterior fluid-filled lesion with hyperechoic metal debris as seen in an extended field of view; and (c) a type 3 lesion; an anterior image showing a large anterior lesion with a central solid echo-texture. GT, greater trochanter; FH, femoral head.

Ultrasound examination protocol

Anterior, lateral, and posterior ultrasound scans were conducted for both hips.[15] The presence or absence of pseudotumours, joint effusions, muscle atrophy, and tendon defects were reported at the time of scanning, using a custom proforma (Supplementary Material Appendix A).

The presence of a coxo-femoral joint effusion was defined as a distance greater than 4 mm,[16] measured anterior at the neck of the femur or prosthesis. Lesions were defined by location (anterior, posterior, medial or lateral), classification (1, 2, or 3; see Table 1) and size (in anterior–posterior, medial–lateral, and cranial–caudal planes). Here, any solid or cystic lesion associated with the MOM prosthesis was defined as a pseudotumour. The surrounding soft tissues were fully visualized in all three positions to identify the presence of pseudotumours.

Both hips were examined for a comparative assessment of muscle atrophy in iliopsoas, gluteus medius, and gluteus minimus muscles as compared to the contralateral side. Muscle atrophy was graded according to a published system[17] on a scale from 0 (no change) to 3 (up to 70% size reduction with marked fatty replacement; Table 1). Tendon diameter (normal or thin), character (hyperechoic, normal or hypoechoic), and presence of ossification were additionally reported.

A pictorial overview of the examination procedure is shown in Fig 1.

Anterior examination

The anterior hip joint was scanned with the patient in the supine position, with mild external rotation at the hip. The anterior synovial recess was identified by placing the transducer in a longitudinal plane parallel to the long axis of the femur and oblique to the femoral neck. The joint space was measured. Scans in the longitudinal and axial planes were used to examine the iliopsoas muscle, tendon, and bursa.

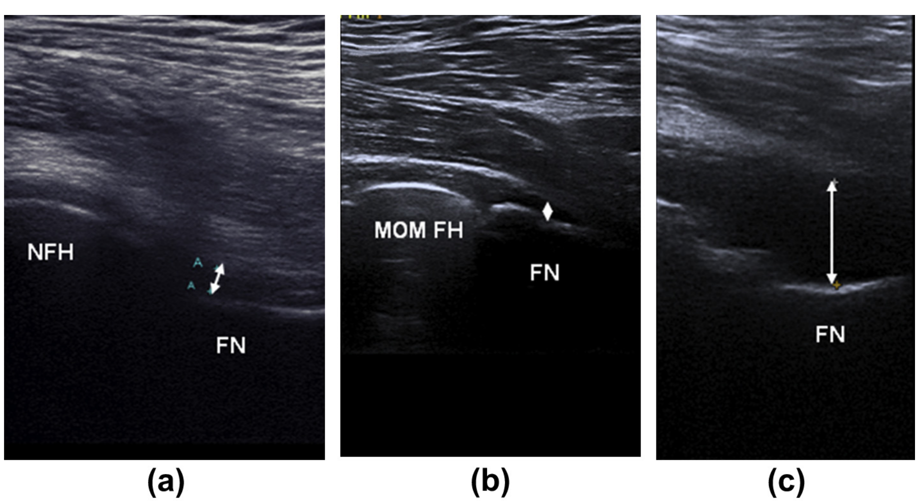

Figure 3 Anterior coxo-femoral joint space (cranial aspect to left of the images). Longitudinal images during anterior examination demonstrate (a) a native hip joint with a normal joint space (white arrow); (b) a prosthetic hip joint with a metal-on-metal hip resurfacing and normal joint space (white arrow); and (c) a prosthetic hip joint with a large joint effusion (white arrow). NFH, native femoral head; MOM FH, metal-on-metal femoral head; FN, femoral neck.

Lateral examination

The lateral hip joint was scanned, with the patient in the lateral decubitus position. Longitudinal and axial scans around the greater trochanter were used to assess the trochanteric bursa for fluid collection and the tendinous attachment of the gluteus medius and minimus muscles. The gluteal muscle bulk was assessed for atrophy using the midpoint position of the muscle to record diameter.

Posterior examination

Posterior examination of the hip was conducted with the patient in the prone position to assess the presence of posterior pseudotumours, using axial and longitudinal scans. Lower frequency transducers were used to obtain adequate penetration through the superficial tissue and gluteus maximus muscle bulk. The posterior joint was visualized by placing the probe posterior to the greater trochanter.[4]

Results

Pseudotumours

Solid or cystic soft-tissue lesions were observed adjacent to MOM hip prostheses and were identified as a cause of unexplained pain following conventional examination and radiography.[8] The term "pseudo-" has been prefixed to these lesions because they do not display features suggestive for malignancy.[4] Pseudotumour has been used in the literature to describe a range of local tissue reactions from synovitis[18] and bursitis,[19] to muscle-destroying solid lesions and lesions associated with periprosthetic osteolysis.[20] Lesions display characteristic histological findings, reported as aseptic lymphocyte-dominated vasculitis associated lesions (ALVAL).[21]

Pseudotumours can be differentiated using ultrasound by their solid or fluid echo-texture, providing useful prognostic information. Solid lesions are associated with a poor clinical outcome, even after the prosthesis has been removed.[22,23]

Pseudotumours were classified on ultrasound in a similar manner to that previously developed for MARS MRI (Fig 2).[11,23] Thus, a type 1 pseudotumour was a cystic lesion with a thin, regular wall and a simple internal fluid echo-texture; a type 2 pseudotumour was a cystic lesion often with an irregular, thickened wall and abnormal internal fluid echo-texture due to the appearance of metal debris (Fig 7); and a type 3 pseudotumour was a complex lesion with a solid internal echo-texture (Fig 8). In the authors' experience, type 1 lesions often represent isolated fluid collections within the trochanteric bursa, as seen during trochanteric bursitis, whereas type 2 lesions are complex in nature and can often communicate with the joint space. It is important to note the presence of metal debris, which can be distinguishable as small dynamic hyperechoic particular material within the fluid.

Joint effusion

A joint effusion was observed as the displacement of the anterior cortex of the joint neocapsule at the femoral neck, with hypoechoic or anechoic fluid collection (Fig 3c). Effusions due to synovitis may be aseptic or septic in nature. Aseptic synovitis can be due to metal particle disease; however, it is difficult to discriminate this from a septic cause.[12] Ultrasound-guided fluid aspiration and culture can determine whether the joint is infected and this influences the surgical technique used during revision; a two-stage revision procedure maybe used to initially eliminate infection.

Musculotendinous disease

The hip abductors, gluteus medius and minimus, are essential for normal gait and mobility. They are often

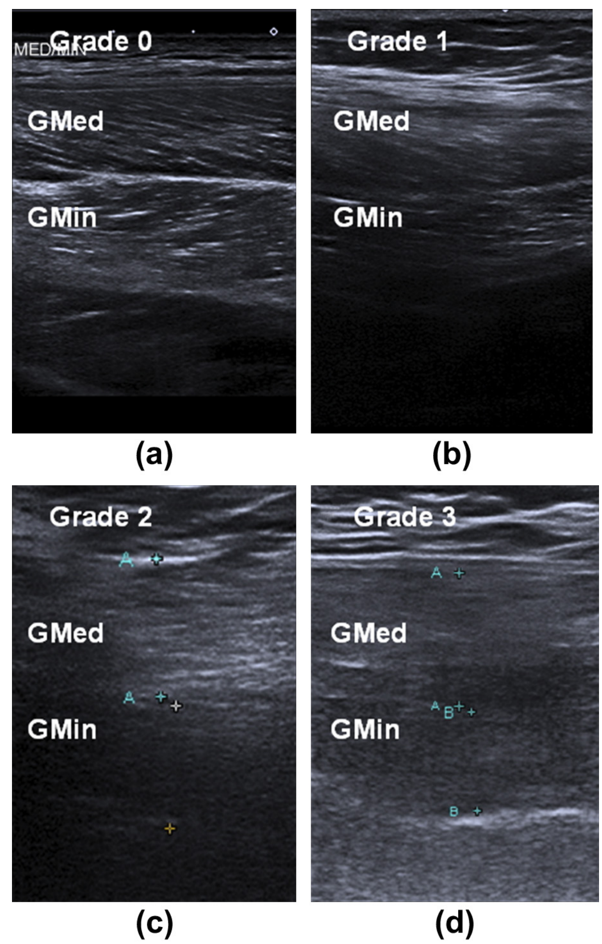

Figure 4 Ultrasound grading of hip abductor muscle atrophy (cranial aspect to left of the images). Lateral longitudinal images of the midpoint position of the gluteus medius and minimus muscles showing consecutive graded muscle atrophy as (a) grade 0 or normal muscular architecture without fatty replacement; (b) grade 1 <30% size reduction with some fatty replacement; (c) grade 2 or 30–70% size reduction with fatty replacement; and (d) grade 3 or extensive loss of muscular architecture with widespread fatty replacement and a decrease of >70% in size as compared to the contralateral hip muscles. GMed, gluteus medius muscle; GMin, gluteus minimus muscle.

atrophied in patients with painful MOM hips and may present a non-specific marker of hip disease.[8]

Ultrasound can easily differentiate between the hypoechoic pinnate structure of normal skeletal muscle and infiltrating hyperechoic fibro-adipose tissue. When associated with a decrease in muscle diameter, this diffuse echogenicity has been used as a reliable indicator of muscle atrophy.[13] The grading system (Fig 4) illustrates the successive loss of hip abductor muscle architecture and size as compared to the contralateral hip.

Tendinosis of the abductor tendons can be seen using ultrasound as tendon thickening and hypoechogenicity (Fig 5b). During calcific tendinosis (Fig 5c) addition hyperechoic calcium deposition may be detected.[12] Complete retraction of these tendons from the greater trochanter would suggest tendinous avulsion, with or without associated hypoechoic or anechoic fluid replacement. Abductor tendon avulsion is often a consequence of the lateral surgical approach, which involves retraction of the tendons to allow access to the joint. Tendon defects can often manifest as muscular insufficiency, lateral pain, and limping on clinical examination.[24]

The iliopsoas tendon is evaluated during the anterior examination, where iliopsoas tendinosis can be observed with features of tendon thickening and hypoechogenicity

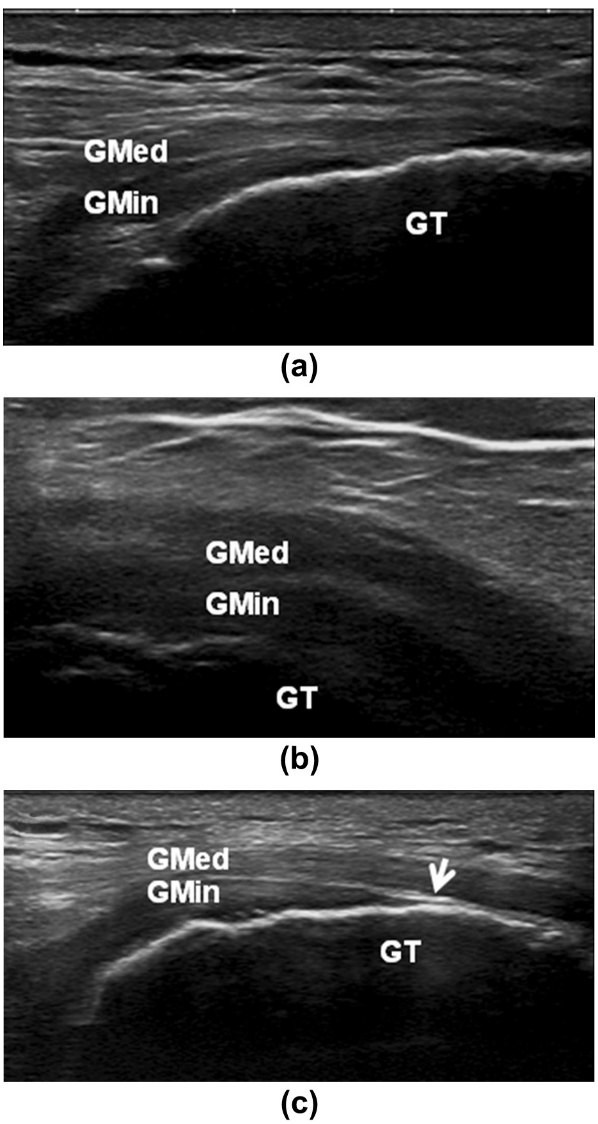

Figure 5 Ultrasound images of the gluteus medius and minimus tendons (cranial aspect to left of images). Lateral longitudinal images of the gluteus medius and minimus attachments onto the greater trochanter with (a) a normal appearance; (b) the hypoechoic appearance of tendinosis; and (c) calcification (white arrow) between the gluteus medius and minimus tendons. GMed, gluteus medius tendon; GMin, gluteus minimus tendon; GT, greater trochanter.

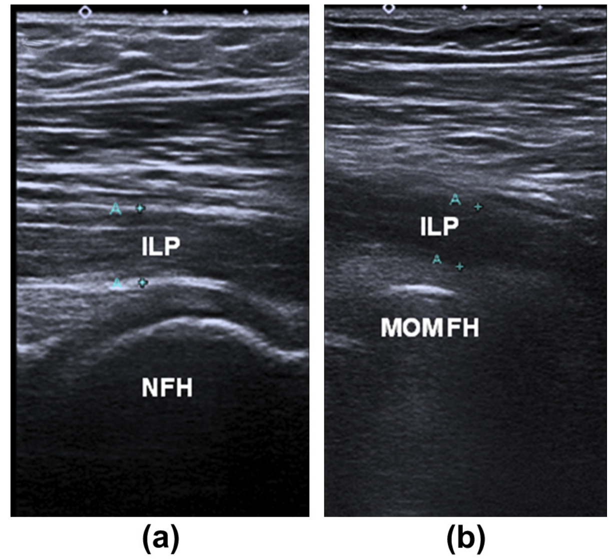

Figure 6 Ultrasound images of the iliopsoas tendon (cranial aspect to left of the images). Anterior longitudinal images showing (a) the iliopsoas tendon running anterior to the native femoral head and (b) tendinosis of the iliopsoas tendon with hypoechogenicity. ILP, iliopsoas tendon; NFH, native femoral head; MOM FH, metal-on-metal femoral head.

Figure 7 Anterior pseudotumour with a complex fluid composition (cranial aspect to left of the image). Anterior image showing a large cystic pseudotumour in longitudinal section, within the iliopsoas bursa and which extends superiorly into the pelvis. The lesion was classified as a type 2 pseudotumour with an internal fluid echotexture and containing dynamic hyperechoic particular material. Hip aspirate showed raised metal ions. FH, femoral head.

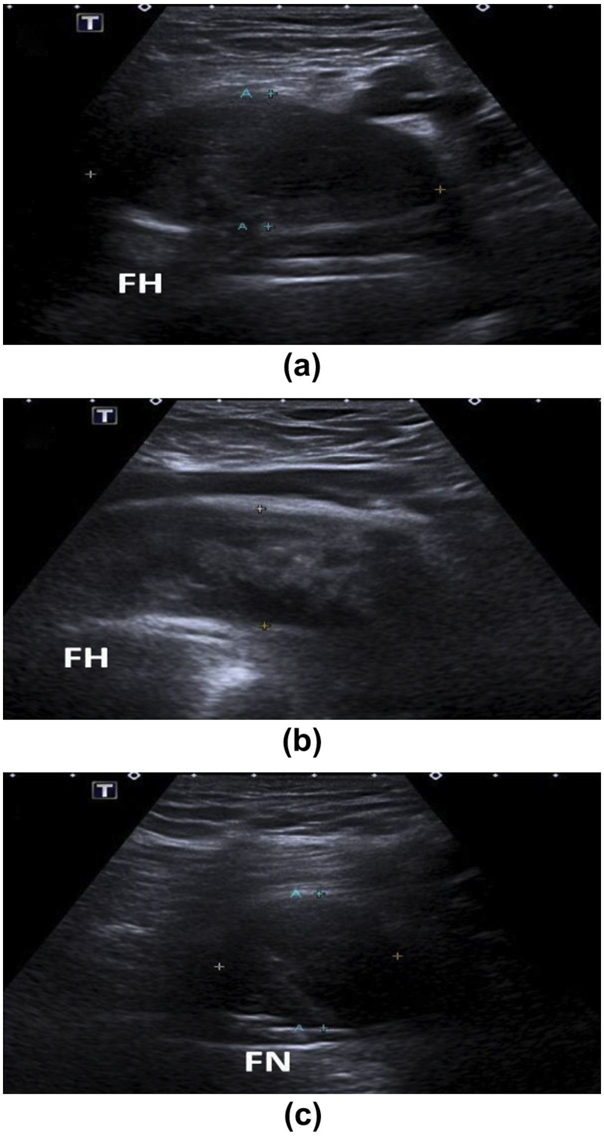

Figure 8 Complex type 3 pseudotumours [cranial aspect to left of image (a) and (b)]. Ultrasound images of type 3 pseudotumours with a complex internal echo-texture (predominantly solid), showing (a) a right anterior pseudotumour in longitudinal section; (b) a left anterior pseudotumour in longitudinal section; and (c) a left posterior pseudotumour in transverse section. FH, femoral head; FN, femoral neck.

(Fig 6b). Severe tendon erosions can manifest as a paradoxical thin or normal-sized tendon, as a result of acetabular component misalignment and impingement.[25]

Discussion

The method of ultrasound scanning presented in this paper used an optimized technique to examine the periprosthetic tissues of MOM hip arthroplasties. The method can be routinely applied within clinical practice. The method was developed to focus on the most common lesions seen with MOM hips, including metal particle disease and unexplained hip pain. However, the thorough ultrasound examination needed to screen for pseudotumours enables synchronous identification of a wide range of other soft-tissue hip disease entities. The method can also be easily applied to hips with other bearing materials (such as metal-on-polyethylene), and enables consensus reporting, which will aid communication between radiologists and between radiologists and surgeons.

As previously suggested, ultrasound is a convenient method for the screening of a large number of patients and can be used during the initial screening of MOM patients for pseudotumours.[6] The classification system defined in this paper was based on established MARS MRI systems and can allow for direct comparison between the two techniques. This is particularly useful for patients in which MARS MRI maybe contraindicated, for example, patients with incompatible metallic implants.

Ultrasound is an operator-dependant technique and is, therefore, limited by interobserver and intra-observer variability. However, an experienced musculoskeletal radiologist should perform the examination to improve reliability.

Additionally, the accuracy of muscle and tendon diameter maybe limited in the absence of a normal anatomical reference for comparison. This is particularly important in patients with bilateral hip replacements during which the contralateral hip may have additional abnormalities.

Nishii et al.[16] highlighted the difficulties in wave penetration during scanning of the posterior joint. The spatial resolution of ultrasound images diminish with depth and, although this effect can be reduced using a lower frequency transducer to improve penetration, it is still often difficult to fully appreciate deeper structures. Therefore, smaller lesions are likely to be missed, particularly during posterior scanning, whereby the large muscle bulk of the gluteus maximus and subcutaneous tissue may obscure view.[16]

In the present report, an optimized and systematic examination protocol is presented, which highlights the value of ultrasound and illustrates the common lesions found in patients with painful MOM hip prostheses. This knowledge is necessary to optimize reporting and improve decision-making for diagnostic radiologists and clinicians.

Disclosures

K.S. is a committee member of Johnson and Johnson.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.crad.2013.02.003.

References

1. FDA: Orthopaedic and Rehabilitation Devices Panel of the Medical Devices Advisory Open Panel Meeting, June 2012. Available at: http://www.fda.gov/AdvisoryCommittees/CommitteesMeetingMaterials/MedicalDevices/MedicalDevicesAdvisoryCommittee/OrthopaedicandRehabilitationDevicesPanel/ucm309184.htm [accessed 08.10.12].

2. Smith AJ, Dieppe P, Vernon K, et al. Failure rates of stemmed metal-on-metal hip replacements: analysis of data from the National Joint Registry of England and Wales. *Lancet* 2012;**379**:1199–204.
3. MHRA. Medical Device Alert: ASR hip replacement implants manufactured by DePuy International Ltd (MDA/2010/069). Available at: http://www.mhra.gov.uk/home/groups/dts-bs/documents/medicaldevicealert/con093791.pdf [accessed 13.04.12].
4. Pandit H, Glyn-Jones S, McLardy-Smith P, et al. Pseudotumours associated with metal-on-metal hip resurfacings. *J Bone Jt Surg Br* 2008;**90**:847–51.
5. Langton DJ, Jameson SS, Joyce TJ, et al. Early failure of metal-on-metal bearings in hip resurfacing and large-diameter total hip replacement: a consequence of excess wear. *J Bone Jt Surg Br* 2010;**92**:38–46.
6. Kwon YM, Ostlere SJ, McLardy-Smith P, et al. "Asymptomatic" pseudotumors after metal-on-metal hip resurfacing arthroplasty: prevalence and metal ion study. *J Arthroplasty* 2011;**26**:511–8.
7. MHRA. Medical Device Alert: all metal-on-metal (MoM) hip replacements (MDA/2012/036). Available at: http://www.mhra.gov.uk/home/groups/dts-bs/documents/medicaldevicealert/con155767.pdf [accessed 08.10.12].
8. Sabah SA, Mitchell AW, Henckel J, et al. Magnetic resonance imaging findings in painful metal-on-metal hips: a prospective study. *J Arthroplasty* 2011;**26**(1): 71–6, 76. e1–2.
9. MHRA. Medical Device Alert: all metal-on-metal (MoM) hip replacements (MDA/2012/008). Available at: http://www.mhra.gov.uk/home/groups/dts-bs/documents/medicaldevicealert/con143787.pdf [accessed 13.04.12].
10. Hayter CL, Potter HG, Su EP. Imaging of metal-on-metal hip resurfacing. *Orthop Clin North Am* 2011;**42**:195–205. viii.
11. Hart AJ, Satchithananda K, Liddle AD, et al. Pseudotumors in association with well-functioning metal-on-metal hip prostheses: a case–control study using three-dimensional computed tomography and magnetic resonance imaging. *J Bone Jt Surg Am* 2012;**94**:317–25.
12. Long SS, Surrey D, Nazarian LN. Common sonographic findings in the painful hip after hip arthroplasty. *J Ultrasound Med* 2012;**31**:301–12.
13. Sofka CM, Haddad ZK, Adler RS. Detection of muscle atrophy on routine sonography of the shoulder. *J Ultrasound Med* 2004;**23**:1031–4.
14. Dawson J, Fitzpatrick R, Carr A, et al. Questionnaire on the perceptions of patients about total hip replacement. *J Bone Jt Surg Br* 1996;**78**:185–90.
15. Fang CS, Harvie P, Gibbons CL, et al. The imaging spectrum of peri-articular inflammatory masses following metal-on-metal hip resurfacing. *Skeletal Radiol* 2008;**37**:715–22.
16. Nishii T, Sakai T, Takao M, et al. Ultrasound screening of periarticular soft tissue abnormality around metal-on-metal bearings. *J Arthroplasty* 2012;**27**:895–900.
17. Bal BS, Lowe JA. Muscle damage in minimally invasive total hip arthroplasty: MRI evidence that it is not significant. *Instr Course Lect* 2008;**57**:223–9.
18. Campbell P, Shimmin A, Walter L, et al. Metal sensitivity as a cause of groin pain in metal-on-metal hip resurfacing. *J Arthroplasty* 2008;**23**:1080–5.
19. De Haan R, Campbell PA, Su EP, et al. Revision of metal-on-metal resurfacing arthroplasty of the hip: the influence of malpositioning of the components. *J Bone Jt Surg Br* 2008;**90**:1158–63.
20. Nikolaou V, Bergeron SG, Huk OL, et al. Evaluation of persistent pain after hip resurfacing. *Bull NYU Hosp Jt Dis* 2009;**67**:168–72.
21. Willert HG, Buchhorn GH, Fayyazi A, et al. Metal-on-metal bearings and hypersensitivity in patients with artificial hip joints. A clinical and histomorphological study. *J Bone Jt Surg Am* 2005;**87**:28–36.
22. Campbell P, Ebramzadeh E, Nelson S, et al. Histological features of pseudotumor-like tissues from metal-on-metal hips. *Clin Orthop Relat Res* 2010;**468**:2321–7.
23. Hauptfleisch J, Pandit H, Grammatopoulos G, et al. A MRI classification of periprosthetic soft tissue masses (pseudotumours) associated with metal-on-metal resurfacing hip arthroplasty. *Skeletal Radiol* 2012;**41**:149–55.
24. Garcia FL, Picado CH, Nogueira-Barbosa MH. Sonographic evaluation of the abductor mechanism after total hip arthroplasty. *J Ultrasound Med* 2010;**29**:465–71.
25. Cobb JP, Davda K, Ahmad A, et al. Why large-head metal-on-metal hip replacements are painful: the anatomical basis of psoas impingement on the femoral head–neck junction. *J Bone Jt Surg Br* 2011;**93**:881–5.