Received:
27 August 2019

Revised:
09 October 2019

Accepted:
17 October 2019

<https://doi.org/10.1259/bjr.20190738>

Cite this article as:

Bäcker HC, Steurer-Dober I, Beck M, Agten CA, Decking J, Herzog RF, et al. Magnetic resonance imaging (MRI) versus single photon emission computed tomography (SPECT/CT) in painful total hip arthroplasty: a comparative multi-institutional analysis. *Br J Radiol* 2020; **93**: 20190738.

FULL PAPER

Magnetic resonance imaging (MRI) versus single photon emission computed tomography (SPECT/CT) in painful total hip arthroplasty: a comparative multi-institutional analysis

^{1,2}HENRIK C. BÄCKER, ³ISABELLE STEURER-DOBER, ²MARTIN BECK, ¹CHRISTOPH A. AGTEN, ⁴JENS DECKING, ⁵RICHARD F. HERZOG, ⁶JEFFREY A. GELLER, ¹UJWAL BHURE, ¹JUSTUS E. ROOS and ¹KLAUS STROBEL

¹Radiology and Nuclear Medicine, Cantonal Hospital Lucerne, Lucerne, Switzerland

²Orthopedic Surgery and Traumatology, Cantonal Hospital Lucerne, Lucerne, Switzerland

³Radiology, Cantonal Hospital Zug, Baar, Switzerland

⁴Orthopedic Surgery, Cantonal Hospital Lucerne, Sursee, Switzerland

⁵Orthopedic Surgery, Cantonal Hospital Lucerne, Wolhusen, Switzerland

⁶Department of Orthopedic Surgery, Columbia University Medical Center/ Presbyterian Hospital, New York, United States

Address correspondence to: Dr Henrik C. Bäcker
E-mail: henrik.baecker@sports-med.org

Objective: To investigate the value of MRI in comparison to single photon emission computed tomography (SPECT)/CT in patients with painful hip arthroplasties.

Methods: A prospective, multi-institutional study was performed. Therefore, 35 consecutive patients (21 female, 14 male, mean age 61.8 ± 13.3 years) with 37-painful hip arthroplasties were included. A hip surgeon noted the most likely diagnosis based on clinical examination and hip radiographs. Then, MRI and SPECT/CT of the painful hips were acquired. MRI and SPECT/CT were assessed for loosening, infection, fracture, tendon pathology and other abnormalities. Final diagnosis and therapy was established by the hip surgeon after integration of MRI and SPECT/CT results. The value of MRI and SPECT/CT for diagnosis was assessed with a 3-point scale (1 = unimportant, 2 = helpful, 3 = essential).

Results: Loosening was observed in 13/37 arthroplasties (6 shaft only, 6 cup only, 1 combined). Sensitivity, specificity, positive predictive value and negative predictive value for loosening of MRI were 86%/88%/60%/100% and of SPECT/CT 93%/97%/90%/100%, respectively.

MRI and SPECT/CT diagnosed infection correctly in two of three patients and fractures in two patients, which were missed by X-ray. MRI detected soft tissue abnormalities in 21 patients (6 bursitis, 14 tendon lesions, 1 pseudotumor), of which only 1 tendon abnormality was accurately detected with SPECT/CT. All 5 arthroplasties with polyethylene wear were correctly diagnosed clinically and with both imaging modalities. MRI and SPECT/CT were judged as not helpful in 0/0%, as helpful in 16%/49% and essential in 84%/51%.

Conclusion: In patients with painful hip arthroplasty SPECT/CT is slightly superior to MR in the assessment of loosening. MRI is far superior in the detection of soft tissue, especially tendon pathologies.

Advances in knowledge: To our knowledge this is the first prospective, multiinstitutional study which compares MRI with SPECT/CT in painful hip arthroplasties. We found that MRI is far superior in the detection of soft tissue pathologies, whereas SPECT/CT remains slightly superior regarding loosening.

INTRODUCTION

Total hip arthroplasty (THA) is the most commonly implanted arthroplasty followed by knee and shoulder joint.¹ In the United States, 277,200 primary total hip arthroplasties were performed in 2017 according to the American Joint Replacement Registry 2017 Annual Report.² With increasing life expectancy and elderly population it is projected that 572,000 hip arthroplasties will be performed in the United

States in 2030.³ According to the Swedish arthroplasty register, approx. 12–13% of arthroplasties need hip revision surgery due to loosening, infection, periprosthetic fracture or other reasons.⁴ Besides imaging with radiographs and planar bone scintigraphy, advanced cross-sectional imaging techniques like CT, MRI and hybrid imaging with single photon emission computed tomography/CT (SPECT/CT) are increasingly used for the evaluation of painful hip arthroplasties.^{5–9}

Since MRI overcame the limitations of artifacts caused by metallic implants with implementation of dedicated metal artifact reduction sequences, it is now possible to adequately evaluate bone and soft tissue abnormalities around hip arthroplasties.^{10,11} SPECT/CT combines the high sensitivity of SPECT for increased bone metabolism and the morphologic information of CT in one exam.¹² Thus, in recent years MRI and SPECT/CT became promising tools for the evaluation of painful hip arthroplasties. However, in this era of medical cost consciousness, it would benefit the surgeon to have an algorithm for ordering more expensive advanced imaging studies when trying to determine the etiology of pain after hip arthroplasty surgery.

To our knowledge, SPECT/CT and MRI has not been compared yet directly in patients with painful hip arthroplasties. Thus, the purpose of our study was to investigate the diagnostic value of MRI in comparison to SPECT/CT in patients with painful hip arthroplasties.

MATERIAL AND METHODS

Study design

In total, 35 consecutive patients with 37 painful hip arthroplasties were prospectively enrolled in this study (21 female, 14 male, mean age 61.8 years, range 32–83). All patients were evaluated by a specialized orthopedic hip surgeon with more than 20 years of experience in hip surgery. Inclusion criteria consisted of patients older than 18 years, who presented in outpatient clinic with painful THA at least 1 year after implantation. Furthermore, in all patients conventional radiographs of the pelvis (anteroposterior) and axial views of the affected hips, MRI and SPECT/CT images were acquired. Mean time interval between SPECT/CT and MRI was 3.2 days. No interventions were undertaken between MR and SPECT/CT imaging. Exclusion criteria were patients with contraindications for MRI imaging (severe claustrophobia, non-MR compatible devices), pregnant females and patients under age of 18. Oral and written informed consent was obtained from all participants before enrolment. The study was approved by the local ethics committee ENKZ 2015–179.

Clinical assessment

After inclusion in the study and detailed clinical investigation including radiographs, the orthopedic surgeon was asked to give the most likely diagnosis responsible for the painful hip arthroplasty before MR and SPECT/CT were acquired. Final diagnosis was established by the same orthopedic surgeon after integration of clinical examination and all imaging modalities (radiographs, MR, SPECT/CT). This final assessment served as reference standard.

Radiographs

Conventional radiographs were acquired in all patients in standard anteroposterior and axial views. The plain film findings with comparison to previous X-rays were incorporated in the initial clinical diagnosis prior to MRI and SPECT/CT. For loosening, polyethylene wear, fractures and other findings established criteria were used as outlined below.^{5,13}

SPECT/CT imaging protocol

Dual phase planar and SPECT/CT images of the pelvis and both femurs including the whole arthroplasty were obtained. The radiotracer ^{99m}Tc-3,3-diphosphono-1,2-propanedicarboxylic acid (^{99m}Tc-DPD) (Teceos, Behringwerke AG, Marburg) was injected intravenously (mean activity 668 MBQ, range 608–730). Early phase planar images of the hips were obtained 5 min after injection (matrix 256 × 256 pixels, field of view: 40 cm) with a hybrid SPECT/CT system with a built-in flat panel CT component (BrightView XCT; Philips Healthcare, Best, The Netherlands). Planar late-phase images of the hips were obtained three hours after radiotracer injection (matrix 256 × 256 pixels, field of view 40 cm). Subsequently, SPECT/CT of the hips was acquired. SPECT was performed in step-and-shoot mode with 64 projections and a frame time of 20 s (SPECT frame format 128 × 128). CT images were acquired with an isotropic voxel size of 1 × 1 × 1 mm (CT slice thickness 1 mm, matrix 512 × 512 mm) with 30 mA and 120 kV and reconstructed with iterative filters. SPECT images were reconstructed with an iterative three-dimensional ordered subsets expectation maximization algorithm (Astonish, Philips). SPECT and CT images were fused automatically with dedicated software (Extended Brilliance Workspace; Philips Healthcare) and reformatted in coronal and sagittal planes.

MRI protocol

All patients were examined on a 1.5 T MR Scanner (Magnetom Aera, Siemens Healthineers, Erlangen, Germany) using a 18-channel body matrix coil and a 32-channel spine coil. Metal artifact reduction sequence (MARS) were used which allows to reduce the size and intensity of susceptibility artifacts from magnetic field distortion. The detailed protocol and sequences are shown in Table 1.

SPECT/CT imaging evaluation

SPECT/CT image were reviewed and reported by a doubly board certified radiologist and nuclear medicine physician specialized in musculoskeletal radiology and with 14 years of experience in musculoskeletal SPECT/CT, blinded to the results of MRI.

- Loosening was diagnosed according to the combined SPECT/CT criteria published by Dobrindt *et al* with a combination of increased uptake around the stem or cup together with lucencies.¹⁴
- Infection was diagnosed in cases with significantly higher vascularity around the arthroplasty in the early phase images and increased uptake in late phase images.
- Periprosthetic fractures were diagnosed in cases with linear increased uptake corresponding to fracture lines in CT.
- Other findings: Polyethylene wear was diagnosed if the head of the arthroplasty was eccentric in combination with osteolytic lesions in the femur or acetabulum.

MRI evaluation

MR images were reviewed and reported by a specialized musculoskeletal radiologist with 15 years of experience in musculoskeletal radiology, blinded to SPECT/CT results.

Table 1. MR protocol sequence description Pat No

Sequence	TIRM	T1	T1	T2	PD
TE	3900	500	520	3550	3880
TR	42	8	7.9	85	26
Orientation	Coronal	Coronal	Axial	Axial	Sagittal
Slice thickness	4 mm	3 mm	4 mm	4 mm	3 mm
Slices	30	30	65	65	35
Matrix	384 × 384	512 × 512	320 × 320	384 × 384	448 × 448
Field of view	370 × 370	370 × 370	220 × 220	220 × 220	260 × 260
Receiver bandwidth (Hz/Pixel)	395	391	391	352	399
Echo train length	25/slice	131/slice	59/slice	9/slice	49/slice
Acquisition time (min.)	4:58	4:25	5:10	5:30	4:50

TE, echo time; TR, repetition time.

- Loosening was diagnosed if a layer of hypointense signal intensity on T_1 weighted images and intermediate to high signal intensity on short-tau inversion recovery- and intermediated-weighted images around the implant with a thickness over 2 mm was present.^{15,16}
- Infection was defined as an increased amount of fluid in the prosthetic joint or in the presence of abscess like formations in the soft tissues.
- Periprosthetic fractures were diagnosed if linear T_1 weighted hypointense signal alterations of the cortex, trabecular bone, or both, with surrounding bone marrow oedema, were present.⁷
- Other findings: the periprosthetic soft tissues were evaluated for bursitis and other extracapsular fluid and/or debris collection (e.g. pseudotumors or infection) as well as for tendon pathology such as tendon rupture, tendinosis or tenosynovitis. The iliopsoas tendon was evaluated for signs of impingement and/or tendinopathy (idiopathic or related to contact with the cup, fixation screw or retained cement); fluid in iliopsoas bursa and/or abnormal signal of the tendon.^{6,15} Polyethylene wear was diagnosed in cases of decentration of the arthroplasty head in craniolateral direction combined with synovitis and/or osteolysis.

Value of SPECT/CT and MR

After final clinical decision making, the surgeon judged MRI and SPECT/CT regarding their importance for his final diagnosis and usefulness for decision making with a 3-point scale: 1 – unimportant, 2 – helpful to 3 – essential.

RESULTS

Patients

The 37 arthroplasties of the 35 included patients showed the following characteristics: 21 left and 16 right sided arthroplasties were affected. The majority of arthroplasties were cementless ($n = 32$) and five were hybrid cemented. Mean age of THA was 7.6 years (SD 8.2 years). In two cases an acetabular reconstruction using an acetabular reinforcement ring with hook was present. Two patients had bilateral painful hip arthroplasties. 19 patients complained about pain at rest with increasing pain under

mechanical load and 16 had pain only under mechanical load. In addition, one patient also complained about crepitation. Only two patients had limited range of motion with restricted hip flexion ≤ 90 degrees. Summary of patient information and results of clinical and imaging assessment is shown in [Tables 2 and 3](#).

Loosening

Isolated shaft loosening was suspected after clinical investigation and radiographs in 17/37 (45.9%), with MR in 12/37 (32.4%) and with SPECT/CT in 8/37 (21.6%); and isolated cup loosening in 8/37 (21.6%), 7/37 (18.9%), 7/37 (18.9%), respectively. According to the reference standard loosening was confirmed in 13 arthroplasties. Sensitivity, specificity, positive predictive value and negative predictive value for shaft loosening, cup loosening and combined loosening of shaft and cup are shown in [Table 4](#). Polyethylene wear was suspected clinically in five patients and visible in all five patients in MR and SPECT/CT and also confirmed as final diagnosis ([Figure 1](#)).

Infection

Infection was initially suspected by the surgeon in 3/37 (8.1%) arthroplasties, on MRI in 2/37 (5.4%) and with SPECT/CT in 2/37 (5.4%) (both the same cases). Eventually, infection was confirmed in two arthroplasties (5.4%) as described in the previous MRI and SPECT/CT findings and excluded in one arthroplasty. One further arthroplasty was diagnosed with joint infection which was false negative in MRI and SPECT/CT.

Fractures

One fracture of the greater trochanter was not visible on radiographs, but detected on MRI and SPECT/CT and finally treated operatively ([Figure 2](#)). In one patient a fracture of the pubic bone was not visible on radiographs but diagnosed with MRI and SPECT/CT.

Soft-tissue disorders

MRI: abductor tendon tears or tendinitis were suspected clinically in 11/37 (29.7%) arthroplasties, on MRI in 12/37 (32.4%), with SPECT/CT in 0/37 (0%) and confirmed in 8/37 (21.6%). Psoas tendinopathy was suspected by the surgeon before MR/

Table 2. Summary of patient information and results of clinical and imaging assessment

Pat. No	Side	Diagnosis based on clinical investigation and x-ray	Diagnosis based on MRI	MR Value	Diagnosis based on SPECT CT	SPECT CT value	Final diagnosis	Further procedure
1	Left	Shaft loosening	Shaft loosening	3	Shaft loosening	3	Arthroplasty loosening	Arthroplasty exchange
2	Left	Shaft loosening Gruen zone one suspected	Shaft loosening suspected	2	Nothing abnormal detected	3	Myalgia gluteus and piriformis muscles	Physiotherapy
3	Left	Cup loosening suspected	Cup loosening, Bursitis iliopsoas, fracture pubic bone	3	Cup loosening fracture pubic bone	3	Cup loosening, fracture pubic bone	Cup exchange
4	Right	Insertional tendinopathy gluteus medius	Insertional tendinopathy abductor muscles	3	Nothing abnormal detected	2	Insertional tendinopathy	Physiotherapy
5	Left	Prosthesis loosening, Polyethylene wear	Shaft loosening, Polyethylene wear, bursitis iliopsoas	3	Shaft loosening, Polyethylene wear	2	Arthroplasty loosening, polyethylene wear	Arthroplasty exchange
6	Right	Low grade infection	Infection, tear of abductor muscles	3	Low grade infection	3	Low grade infection suspected	Arthroplasty exchange versus second opinion
7	Left	Shaft loosening Gruen zone 1–2	Shaft loosening	3	Shaft loosening	2	Shaft loosening	Shaft exchange or conservative
8	Right	Neuralgia paresthetica suspected	Nothing abnormal detected	3	Nothing abnormal detected	3	Unclear	Physiotherapy
9	Left	Shaft loosening Gruen zone 1–2,7 and Polyethylene wear	Cup loosening, polyethylene wear, bursitis iliopsoas, gluteal muscle atrophy	3	Cup loosening, polyethylene wear	2	Cup loosening and Polyethylene wear	Cup exchange
10	Right	Unclear	Bursitis ischiofemoralis	3	Nothing abnormal detected	2	Unclear	Wait patiently
11	Left	Unclear; ectopic ossifications; Impingement	Gluteal muscle atrophy	2	Nothing abnormal detected	3	Unclear	Lumbar spine evaluation
12	Left	Cup loosening and implant failure with dislocation of the femoral head, polyethylene wear	Cup loosening and polyethylene wear	2	Cup loosening, polyethylene wear	3	Cup loosening, polyethylene wear	Cup exchange
13	Left	Pseudotumor	Pseudotumor	3	Nothing abnormal detected	2	Pseudotumor	Arthroplasty exchange
14	Left	Shaft loosening	Shaft loosening	3	Shaft loosening	3	Shaft loosening	Shaft exchange
15	Left	Unclear corticalis hypertrophica; shaft loosening suspected	Insertional tendinopathy abductor muscles	3	Shaft loosening	2	Lumbar disc hernia	Physiotherapy hip, lumbar spine surgery
16	Right	Psoas irritation, shaft loosening Gruen zone 1–2, 7	Abductor tendon tear	3	Nothing abnormal detected	2	Abductor tendon tear, psoas irritation, bursitis iliopsoas	Injection bursa iliopsoas
17	Left	Shaft loosening suspected	Shaft loosening	3	Beginning shaft loosening, foreign body granuloma	3	Beginning shaft loosening	Wait patiently
18	Right	Cup loosening	Cup loosening	2	Cup loosening	3	Cup loosening	Cup exchange

(Continued)

Table 2. (Continued)

Pat. No	Side	Diagnosis based on clinical investigation and x-ray	Diagnosis based on MRI	MR Value	Diagnosis based on SPECT CT	SPECT CT value	Final diagnosis	Further procedure
19	Left	Iliotibial tract irritation,	Iliopsoas tendinopathy	3	Nothing abnormal detected	3	Iliopsoas tendinopathy	Hip arthroscopy
	Right	Abductor insufficiency	Partial abductor tendon tear	3	Nothing abnormal detected	3	Partial abductor tendon tear	Physiotherapy
20	Left	Insertional tendinopathy tuber ischiadicum, iliopsoas irritation	Scar tissue trochanter major	3	Nothing abnormal detected	2	Tuber ischiadicum irritation	Injection tuber ischiadicum
21	Right	Iliopsoas tendinopathy and reactive bursitis	Slight overlaying cup, iliopsoas tendon friction	3	Nothing abnormal detected	2	Slight overlaying cup, lumbago	MRI lumbar spine, physiotherapy
	Left	Iliopsoas tendinopathy and reactive bursitis	Iliopsoas tendinopathy and friction	3	Nothing abnormal detected	2	Iliopsoas tendinopathy	MRI lumbar spine, physiotherapy
22	Left	Arthroplasty loosening	Irritation of the iliotibial band	3	Nothing abnormal detected	2	Myalgia	Physiotherapy
23	Right	Insertional tendinopathy gluteus medius, and major trochanter	Abductor tendon tear	3	Nothing abnormal detected	2	Abductor tendon tear	Surgery—refixation
24	Right	Insertional abductor tendinopathy and partial rupture	Shaft loosening	3	Slight cup overlaying	3	Unclear	Physiotherapy
25	Left	Haft loosening Gruen zone one and Rectus femoris, Iliopsoas irritation	Shaft loosening, Bursitis iliopectinea	2	Cup loosening suspected	3	Cup loosening, bursitis iliopectinea	Cup exchange and injection bursa iliopectinea
26	Right	Low grade infection, ischiofemoral impingement	Abductor tendon tear	3	Nothing abnormal detected	2	Ischiofemoral impingement	Diagnostic hip puncture followed by arthroplasty exchange
27	Left	Prosthesis loosening	Bursitis iliopectinea	3	Nothing abnormal detected	2	Abductor atrophy	Physiotherapy
28	Left	Insertional tendinopathy rectus femoris and bursitis iliopectinea	Nothing abnormal detected	3	Nothing abnormal detected	3	Myalgia	Physiotherapy
29	Right	Shaft loosening Gruen zone 7	Shaft loosening with polyethylene wear	3	Polyethylene wear	3	Polyethylene wear	Physiotherapy
30	Left	Muscular dysbalance, proximal shaft loosening	Early arthroplasty loosening, infection	3	Infection	2	Early arthroplasty loosening, low grade infection	Arthroplasty exchange
31	Left	Cup and/or shaft loosening, polyethylene wear	Arthroplasty loosening, greater trochanter fracture, polyethylene wear	2	Cup loosening, polyethylene wear, greater trochanter fracture	3	Arthroplasty loosening, polyethylene wear, greater trochanter fracture	Arthroplasty exchange and trochanter re-fixation

(Continued)

Table 2. (Continued)

Pat. No	Side	Diagnosis based on clinical investigation and x-ray	Diagnosis based on MRI	MR Value	Diagnosis based on SPECT CT	SPECT CT value	Final diagnosis	Further procedure
32	Right	Iliopsoas irritation, shaft loosening Gruen zone 1, 7	Shaft and cup loosening, acetabular screw in the pelvis adjacent to iliac vessels	3	Acetabular screw in the pelvis	2	Irritation iliopsoas	Cup exchange
33	Right	Insertional tendinosis	Nothing abnormal detected	3	Beginning shaft loosening	3	Enthesopathy	Stimulating X-ray therapy or cutaneous femoris lateralis nerve release
34	Right	Prosthesis loosening and muscle contractures	Scar tissue between trochanter major and abductor muscles	3	Nothing abnormal detected	3	Muscle irritation	Physiotherapy
35	Right	Acetabular lesion	Tumor relapse	3	Tumor subacetabular, loosening shaft	2	Arthroplasty loosening and tumor relapse	Biopsy, surgery

SPECT/CT imaging in 5/37 (13.5%) arthroplasties, with MRI in 3/37 (8.1%), with SPECT/CT in 1/37 (2.7%) and finally confirmed in 4/37 (10.8%). In one case where an overlaying cup was diagnosed, iliopsoas tendinopathy was identified as well (Figure 3). Bursitis was suspected by the surgeon in 3/37 (8.1%) arthroplasties, on MRI in 6/37 (16.2%) and with SPECT/CT in 0 (0%) and finally confirmed in 2 out of 37 (5.4%).

Conclusions and proposed treatment

Based on the diagnosis, surgery was indicated in 14 arthroplasties to change either the cup (six patients), shaft (two patients) or both (six patients). In addition, one hip arthroscopy and one abductor tendon refixation were indicated. Conservative treatment/ physiotherapy was recommended in 15 arthroplasties. Additionally, in two patients no specific therapy was recommended and in one patient further evaluation of the spine was advised. Corticosteroid infiltrations were recommended and performed in three trochanteric or iliopectinea bursae and external radiation therapy in one case with enthesiopathy.

Value of SPECT/CT and MR

The value of MRI and SPECT/CT for clinical decision-making was judged by the surgeon as not helpful in 0% (both modalities),

as helpful in 16.2 and 48.6% and essential in 83.8 and 51.4%, respectively (Figure 4).

DISCUSSION

In this first direct comparison between MRI with MARS protocol and SPECT/CT in patients with painful hip arthroplasties, we showed that both modalities provide complementary information. SPECT/CT might serve as reference standard for loosening, positioning of the components and visualization of osteolysis and bone structure. However, SPECT/CT is clearly limited in the diagnosis of soft tissue and tendon abnormalities. MRI excels SPECT/CT for the detection of bursitis, pseudotumors and tendinopathy. Iliopsoas tendinopathy is observed in about 4.3% patients presenting with painful hip arthroplasty, but substantially higher in our study population (13.5%).¹⁷ Abductor (gluteus medius and minimus) tendon tears and greater trochanteric bursitis can cause lateral hip pain after hip replacement and can be assessed by ultrasound or MRI.^{18,19} No difference was seen in MRI and SPECT/CT regarding the diagnosis of infection. However, since only two infected arthroplasties were observed in this study no representative insights could be obtained. Of note, infection after hip arthroplasty is difficult to diagnose on imaging alone and typically combines serologic testing of inflammatory

Table 3. Absolute numbers of pathologies found suspected in X-ray, SPECT/CT, MRI and final diagnosis

	Clinical diagnosis with X-ray	SPECT/CT	MRI	Final diagnosis
Loosening	20	13	16	13
Infection	3	2	2	2
Fracture	0	2	2	2
Tendinopathy/tear	11	1	9	9
Bursitis	3	0	6	2

SPECT, single photon emission computed tomography.

Table 4. Performance of different modalities regarding shaft and cup loosening

	Sensitivity	Specificity	PPV	NPV
MRI overall	86%	88%	60%	100%
MRI cup	86%	97%	90%	100%
MRI shaft	86%	80%	50%	100%
SPECT CT overall	93%	97%	90%	100%
SPECT CT cup	100%	100%	100%	100%
SPECT CT shaft	86%	93%	80%	100%

NPV, negative predictive value; PPV, positive predictive value; SPECT, single photon emission computed tomography.

markers (sedimentation rate and c-reactive protein), a diagnostic aspiration of the joint as well as possible biopsy for microbiological testing.

SPECT/CT in the work-up of painful hip arthroplasties is increasingly used due to wider availability of SPECT/CT scanners in larger hospitals. Nevertheless, studies are still sparse. Dobrindt et al investigated 23 patients with painful hip arthroplasties and reported that the cause of pain could be identified with SPECT/CT in 13 of 18 cases.¹⁴ Loosening was correctly assessed in all cases. In that paper the authors provided combined SPECT/CT criteria for loosening of the acetabular and femoral component, which we also used in our study. Tam et al described in their review article useful criteria for abnormalities causing pain after hip arthroplasties, such as infection, periprosthetic fractures, heterotopic ossifications

and polyethylene wear.²⁰ Berber et al investigated SPECT/CT in 15 patients with painful hip arthroplasties and showed that SPECT/CT changed the management decision in 13 patients (68%) while loosening was the most frequent SPECT/CT diagnosis.²¹ Arican et al reported superiority of SPECT/CT over planar/ SPECT in 20 hip arthroplasties with sensitivities of 94.1 and 93.3% for loosening of the femoral component and 89.4 vs 57.8% for the acetabular component.²² With the newest generation of SPECT/CT scanners implementation of metal artifact suppressed diagnostic CT becomes available for improved evaluation of bone and soft tissue structures around the metal implants.¹² Further important information of SPECT/CT can be obtained if three-dimensional reconstructions and measurements of the component positions are provided as shown in a recent study.²³ Implementation of quantification and reconstruction algorithms such as xBone SPECT/CT in daily routine

Figure 1. A 68-year-old female patient. 28 years old asymptomatic arthroplasty on the right side and symptomatic 33 years old arthroplasty on the left side. Radiographs (A) show decentration of the arthroplasty head (long arrow) as a sign for polyethylene wear and a radiolucent rim around the shaft (short arrow) as sign for shaft loosening. Planar late phase bone scintigraphy image (B) and fused coronal SPECT/CT (G) show slightly increased uptake around the shaft (short arrows) and polyethylene wear (long arrow). Coronal TIRM (D, F) and T1 images show effusion with chronic synovitis (F) caused by polyethylene wear (arrow). Radiographs (C) after arthroplasty exchange. SPECT, single photon emission computed tomography.

Figure 2. An 84-year-old female patient with 8 years old arthroplasty and pain. Radiographs (A) without evidence for fracture. Early phase (C), late phase (D), coronal CT (G) and fused SPECT/CT (H) with fracture of the greater trochanter (arrow) and increased linear uptake (arrows). MRI with coronal TIRM (E) and T1 (F) also showing the greater trochanter fracture (arrow). Radiographs (B) after fixation of trochanter and cup exchange. SPECT, single photon emission computed tomography.

Figure 3. A 74-year-old female patient with 9 year old arthroplasty and pain in the left groin. Radiograph (A) without signs of loosening. Planar bone scintigraphy (C) and SPECT/CT (D) without signs for loosening but screw protrusion in the pelvic soft tissues (arrow). Axial (E) and sagittal (F) T1 MR images showing conflict of psoas tendon with cup rim causing deviation and tendinopathy (arrows). Radiographs (B) after cup exchange. SPECT, single photon emission computed tomography.

Figure 4. Impact of SPECT/CT and MRI for final diagnosis as judged by the referring orthopedic surgeon. SPECT, single photon emission computed tomography.

bone and joint SPECT/CT imaging are further promising tools for the assessment of painful arthroplasties.²⁴

Interestingly, Robinson et al compared MRI with metal artifact reduction sequences with CT in 50 patients with painful arthroplasty. In that study, MRI was superior in pseudotumor detection (50% detection rate versus 22% with CT) and classification of pseudotumors.²⁵ For high risk patients including high serum cobalt, high cup inclination of more than 45° and female gender, the incidence of pseudotumors is up to 59 vs 0% in low risk patients based on MARS-MRI.²⁶ For the identification of osteolysis, CT had a clearly higher detection rate (30%) compared to MR (8%). Furthermore, Robinson showed that CT was unreliable for the assessment of muscle atrophy. These authors concluded that CT is an unsuitable substitute for MR regarding soft tissue abnormalities associated with hip arthroplasties.

Other studies which investigated the usefulness of MRI and related adverse local tissue reaction after hip arthroplasty reported a sensitivity of 86.4% and specificity of 60.2%.²⁷ Nowadays MARS-MRI provides a good tool to overcome artifacts of metal implants especially in orthopaedic surgery and traumatology in comparison to MRIs.²⁸ This sequence has broadened the indications and usefulness in diagnostics. Therefore, lower magnetic strengths are required (1.5 T), shorter echo spacing, short-tau inversion recovery for fat suppression, spin echo instead of gradient echo as well as smaller water-fat shift and thinner slices.²⁹ Further research is focusing on newer sequences which include slice-encoding metal artifact correlation and view-angle tilting turbo spin echo MR, which show even higher

resolution and reduces metal artifact significantly in comparison to the normal turbo spin echo MRI.^{30–32}

In our study MRI with metallic artifact reduction protocol provided slightly more value to the surgeon for the diagnosis and clinical decision-making than SPECT/CT. This result represents the opinion of experienced hip surgeons in one institution only and might be biased by individual and institutional preference. Our results might help in the selection of advanced imaging and are in line with the proposed imaging flowchart published recently¹²: if conventional radiography is inconclusive and clinical examination favors a soft tissue pathology such as tenderness over the abductors or trochanteric bursa as the pain generator in patients with hip arthroplasties MARS-MRI or ultrasound might be the best second line imaging modality. If loosening, periprosthetic fractures or heterotopic calcifications are suspected, SPECT/CT might be the better imaging modality (Figure 5).³³ Similar findings were described in girdlestone arthroplasty with higher specificity and equivalent sensitivity for SPECT/CT compared with MRI (SPECT/CT sensitivity 90% specificity 94% respectively 90 and 87% for MRI).³⁴ Because of the complementary information obtained by both techniques, the concurrent use might be necessary in some patients. MRI may also be contraindicated in patients with severe claustrophobia, metallic implants such as cardiac pacemakers or stimulators, which is not uncommon in this population. A limitation of our study was the relatively small sample size. Another limitation was that only one reader assessed the MRI images and SPECT/CT images, respectively. Hence, the final diagnosis might be biased on the readers' experience. However, as both readers were highly specialized, we

Figure 5. Diagnostic algorithm for painful hip arthroplasty adopted from van den Wyngaert et al.; * followed by dedicated radi-nuclide infection imaging if required.¹²

are convinced that a multireader setup would not substantially improve our results.

In conclusion, in patients with painful hip arthroplasties SPECT/CT is slightly superior to MRI in the assessment of loosening. However, only MRI detects soft tissue pathologies such as abductor or psoas tendon lesions accurately and its value to the surgeon was rated higher compared to SPECT/CT. The hip surgeon should likely initially evaluate the painful hip with plain radiographs and laboratory serologic testing. If the diagnosis is still elusive, this generalized approach of loosening versus soft-tissue pathology should be considered when ordering advanced imaging studies.

KEY POINTS

- (1) There is an increasing number in hip arthroplasty revision surgeries.
- (2) The diagnosis of prosthesis infection or loosening include conventional imaging as well as hip puncture, however the importance of magnetic resonance imaging and SPECT/CT is increasing.
- (3) Based on our study, SPECT/CT is still slightly superior to MRI in the assessment of loosening, however MRI is far superior in the detection of soft tissue pathologies and was found to give more informative value to the orthopaedic surgeon.

REFERENCES

1. López-López JA, Humphris RL, Beswick AD, Thom HHZ, Hunt LP, Burston A, et al. Choice of implant combinations in total hip replacement: systematic review and network meta-analysis. *BMJ* 2017; **359**: j4651. doi: <https://doi.org/10.1136/bmj.j4651>
2. Fourth AJRR Annual Report on Hip and Knee Arthroplasty Data. American joint replacement registry 2017 annual report. 2018.
3. Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. *J Bone Joint Surg Am* 2007; **89**: 780–5. doi: <https://doi.org/10.2106/JBJS.F.00222>
4. Karachalios T, Komnos G, Koutalos A. Total hip arthroplasty: survival and modes of failure. *EFORT Open Rev* 2018; **3**: 232–9. doi: <https://doi.org/10.1302/2058-5241.3.170068>
5. Fritz J, Lurie B, Miller TT. Imaging of hip arthroplasty. *Semin Musculoskelet Radiol* 2013; **17**: 316–27. doi: <https://doi.org/10.1055/s-0033-1348098>
6. Fritz J, Lurie B, Miller TT, Potter HG. Mr imaging of hip arthroplasty implants. *Radiographics* 2014; **34**: E106–32. doi: <https://doi.org/10.1148/rg.344140010>
7. Khodarahmi I, Fritz J. Advanced MR imaging after total hip arthroplasty: the clinical impact. *Semin Musculoskelet Radiol* 2017; **21**: 616–29. doi: <https://doi.org/10.1055/s-0037-1606137>
8. Talbot BS, Weinberg EP. Mr imaging with Metal-suppression sequences for evaluation of total joint arthroplasty. *Radiographics* 2016; **36**: 209–25. doi: <https://doi.org/10.1148/rg.2016150075>
9. Strobel K, Steurer-Dober I, Huellner MW, Veit-Haibach P, Allgayer B. Importance of SPECT/CT for knee and hip joint prostheses. *Radiologe* 2012; **52**: 629–35. doi: <https://doi.org/10.1007/s00117-011-2270-3>
10. Twair A, Ryan M, O'Connell M, Powell T, O'Byrne J, Eustace S. Mr of failed total hip replacement caused by abductor muscle avulsion. *AJR Am J Roentgenol* 2003; **181**: 1547–50. doi: <https://doi.org/10.2214/ajr.181.6.1811547>
11. Sutter R, Ulbrich EJ, Jellus V, Nittka M, Pfirrmann CWA. Reduction of metal artifacts in patients with total hip arthroplasty with slice-encoding metal artifact correction and view-angle tilting MR imaging. *Radiology* 2012; **265**: 204–14. doi: <https://doi.org/10.1148/radiol.12112408>
12. Van den Wyngaert T, Paycha F, Strobel K, Kampen WU, Kuwert T, van der Bruggen W, et al. SPECT/CT in postoperative painful hip arthroplasty. *Semin Nucl Med* 2018; **48**: 425–38. doi: <https://doi.org/10.1053/j.semnuclmed.2018.05.002>
13. Chang CY, Huang AJ, Palmer WE. Radiographic evaluation of hip implants. *Semin Musculoskelet Radiol* 2015; **19**: 12–20. doi: <https://doi.org/10.1055/s-0034-1396763>
14. Dobrindt O, Amthauer H, Krueger A, Ruf J, Wissel H, Grosser OS, et al. Hybrid SPECT/CT for the assessment of a painful hip after uncemented total hip arthroplasty. *BMC Med Imaging* 2015; **15**: 18. doi: <https://doi.org/10.1186/s12880-015-0056-1>
15. Hayter CL, Koff MF, Potter HG. Magnetic resonance imaging of the postoperative hip. *J Magn Reson Imaging* 2012; **35**: 1013–25. doi: <https://doi.org/10.1002/jmri.23523>
16. Agten CA, Sutter R, Pfirrmann CWA. Ct and MRI of hip arthroplasty. *Radiologe* 2014; **54**: 715–25quiz 26. doi: <https://doi.org/10.1007/s00117-014-2693-8>
17. Bricteux S, Beguin L, Fessy MH. Iliopsoas impingement in 12 patients with a total hip arthroplasty. *Rev Chir Orthop Reparatrice Appar Mot* 2001; **87**: 820–5.

18. Agten CA, Sutter R, Dora C, Pfirrmann CWA. Mr imaging of soft tissue alterations after total hip arthroplasty: comparison of classic surgical approaches. *Eur Radiol* 2017; **27**: 1312–21. doi: <https://doi.org/10.1007/s00330-016-4455-7>
19. Pfirrmann CWA, Notzli HP, Dora C, Hodler J, Zanetti M. Abductor tendons and muscles assessed at MR imaging after total hip arthroplasty in asymptomatic and symptomatic patients. *Radiology* 2005; **235**: 969–76. doi: <https://doi.org/10.1148/radiol.2353040403>
20. Tam HH, Bhaludin B, Rahman F, Weller A, Ejindu V, Parthipun A. SPECT-CT in total hip arthroplasty. *Clin Radiol* 2014; **69**: 82–95. doi: <https://doi.org/10.1016/j.crad.2013.08.003>
21. Berber R, Henckel J, Khoo M, Wan S, Hua J, Skinner J, et al. Clinical usefulness of SPECT-CT in patients with an unexplained pain in metal on metal (mom) total hip arthroplasty. *J Arthroplasty* 2015; **30**: 687–94. doi: <https://doi.org/10.1016/j.arth.2014.11.019>
22. Arıcan P, Okudan Tekin B, Şefizade R, Naldöken S, Baştuğ A, Özkurt B. The role of bone SPECT/CT in the evaluation of painful joint prostheses. *Nucl Med Commun* 2015; **36**: 931–40. doi: <https://doi.org/10.1097/MNM.0000000000000348>
23. Barthassat E, Afifi F, Konala P, Rasch H, Hirschmann MT. Evaluation of patients with painful total hip arthroplasty using combined single photon emission tomography and conventional computerized tomography (SPECT/CT) - a comparison of semi-quantitative versus 3D volumetric quantitative measurements. *BMC Med Imaging* 2017; **17**: 31. doi: <https://doi.org/10.1186/s12880-017-0204-x>
24. Duncan I, Ingold N. The clinical value of xSPECT/CT bone versus SPECT/CT. A prospective comparison of 200 scans. *Eur J Hybrid Imaging* 2018; **2**: 4. doi: <https://doi.org/10.1186/s41824-017-0024-9>
25. Robinson E, Henckel J, Sabah S, Satchithananda K, Skinner J, Hart A. Cross-Sectional imaging of metal-on-metal hip arthroplasties. can we substitute Mars MRI with CT? *Acta Orthop* 2014; **85**: 577–84. doi: <https://doi.org/10.3109/17453674.2014.964618>
26. Smeeke C, Schouten BJM, Nix M, Ongkiehong BF, Wolterbeek R, van der Wal BCH, et al. Pseudotumor in metal-on-metal hip arthroplasty: a comparison study of three grading systems with MRI. *Skeletal Radiol* 2018; **47**: 1099–109. doi: <https://doi.org/10.1007/s00256-018-2873-0>
27. Smeeke C, Schouten BJM, Nix M, Ongkiehong BF, Wolterbeek R, van der Wal BCH, et al. Pseudotumor in metal-on-metal hip arthroplasty: a comparison study of three grading systems with MRI. *Skeletal Radiol* 2018; **47**: 1099–109. doi: <https://doi.org/10.1007/s00256-018-2873-0>
28. Guermazi A, Miaux Y, Zaim S, Peterfy CG, White D, Genant HK. Metallic artefacts in MR imaging: effects of main field orientation and strength. *Clin Radiol* 2003; **58**: 322–8. doi: [https://doi.org/10.1016/S0009-9260\(02\)00540-8](https://doi.org/10.1016/S0009-9260(02)00540-8)
29. Hargreaves BA, Worters PW, Pauly KB, Pauly JM, Koch KM, Gold GE. Metal-Induced artifacts in MRI. *AJR Am J Roentgenol* 2011; **197**: 547–55. doi: <https://doi.org/10.2214/AJR.11.7364>
30. Ma Y, Zuo P, Nittka M, Cheng X, Shao H, Wang C. Comparisons of slice-encoding metal artifact correction and view-angle tilting magnetic resonance imaging and traditional digital radiography in evaluating chronic hip pain after total hip arthroplasty. *J Orthop Translat* 2018; **12**: 45–54. doi: <https://doi.org/10.1016/j.jot.2017.11.002>
31. Deligianni X, Bieri O, Elke R, Wischer T, Egelhof T. Optimization of scan time in MRI for total hip prostheses: SEMAC tailoring for prosthetic implants containing different types of metals. *Rofo* 2015; **187**: 1116–22. doi: <https://doi.org/10.1055/s-0041-104893>
32. Molière S, Dillenseger J-P, Ehlinger M, Kremer S, Bierry G. Comparative study of fat-suppression techniques for hip arthroplasty MR imaging. *Skeletal Radiol* 2017; **46**: 1209–17. doi: <https://doi.org/10.1007/s00256-017-2670-1>
33. Williams TR, Puckett ML, Denison G, Shin AY, Gorman JD. Acetabular stress fractures in military endurance athletes and recruits: incidence and MRI and scintigraphic findings. *Skeletal Radiol* 2002; **31**: 277–81. doi: <https://doi.org/10.1007/s00256-002-0485-0>
34. Diederichs G, Hoppe P, Collettini F, Wassilew G, Hamm B, Brenner W, et al. Evaluation of bone viability in patients after girdlestone arthroplasty: comparison of bone SPECT/CT and MRI. *Skeletal Radiol* 2017; **46**: 1249–58. doi: <https://doi.org/10.1007/s00256-017-2692-8>