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Musculoskeletal Imaging REVIEW

Evaluation of diagnostic imaging modalities for complications after total hip arthroplasty

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ABSTRACT

Hip replacement surgery has evolved in line with advancements in implant technology and quality of surgical technique. Radiographs remains first imaging technique used for patient evaluation followed by ultrasonography, computed tomography, magnetic resonance imaging, arthrography, aspiration and nuclear scan techniques. Mechanical loosening, polyethylene wear–induced osteolysis, adverse local tissue reaction due to metal wear debris, infection, fractures, heterotopic ossification, tendinopathy and nerve damage are common causes of painful hip arthroplasty. The radiologist must effectively detect critical concerns with imaging tools while also remaining up to date on additional complications related with advances in surgical technique, implant design, and innovative materials. The present study reviews extensively the clinical and imaging modalities that can be used to better detect complications after hip arthroplasty replacement.

KEY WORDS

hip arthroplasty, imaging, postoperative complications, radiography

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Introduction

Total hip arthroplasty (THA) is the most successful orthopaedic procedure performed during the 21st century [1]. Modern surgical techniques and high quality of implants have resulted in long lasting survival rates, of approximately 87.5% after 10 years [2]. Most often reason for revision of THA is instability, dislocation, septic and aseptic loosening [3]. Mechanical pain is the major clinical symptom of serious complications, but mild complications like metal hypersensitivity can be usually asymptomatic. Accurate patient history and clinical evaluation should be accompanied by the right imaging modalities. Therefore, application of the appropriate imaging method is of key importance (Table 1).

Overview of Imaging Modalities

Radiography: Radiographic evaluation is the first line of treatment for every symptomatic and asymptomatic patient, for evaluating total hip arthroplasties [2]. Their main use is the evaluation of implant position and presence of wear or migration [5, 6]. Radiographic loosening signs can be found even in asymptomatic patients. Before revision arthroplasty, standard and additional views (like Lowenstein lateral or oblique views) can be valuable [7].

Arthrography: Needle placement is assisted by fluoroscopy, computed tomography (CT), or ultrasound (US). Contrast agent is ingrained into the joint to distinguish sinus tracts, fistulae and collections that interface to the joint and can help assess component loosening and tissue sampling [8].

Computed tomography: Long lasting metal arthroplasties, older scanners and imaging techniques can pose a serious problem with significant image degradation and artifacts. Modern dual energy CT scanners and up-to-date imaging protocols have diminished artifacts, radiation doses and can help in better evaluation of bone, cement and soft issues around the prosthesis, remaining a useful tool for diagnosing osteolysis, hardware position, wear, fractures, heterotopic ossification, hematomas and fluid collections [9-12].

Quantitative CT: Remains a valuable research tool that allows the assessment and trabecular and cortical bone around the implants [13, 14].

Magnetic resonance imaging (MRI): Modern MRI techniques and protocols have decreased metal artifacts and can give precise information about structures as joint capsule, soft tissues, nerves, vessels, tendons and muscles around implants [8, 15-20].

Dual-energy x-ray absorptiometry: Mainly used as a research tool, in order to measure changes in bone density around the implants and its relation with various component design [21]

Bone scan: Useful and sensitive tool for identification of a failed arthroplasty due to infection or loosening, when there is present increased uptake on the bone scan [22].

Gallium scan: Gallium-67 citrate intake is increased both in septic environment and in aseptic areas of new bone formation, and is usually used in comparison with bone scan [22].

Labelled leukocyte (WBC) and WBC/Tc-99m sulphur colloid bone marrow scanning: Increased numbers of leukocytes are found in suspected septic environment like acute or chronic osteomyelitis, abscesses and septic joints. Normally, leukocytes can be found in bone marrow, but differential diagnosis could be tricky when implants, fractures, heterotopic bone take place and bone marrow scans should be combined with WBC scans for improved accuracy (around 90%) [23].

Nuclear arthrography: Injection of radiopharmaceuticals is usually performed with bone scanning with various indium-111 complexes for evaluation of hardware loosening.

Fluorine-18-fluoro-deoxyglucose (FDG) positron emission tomography (PET): Increased accumulation of FDG is found in septic situations and in granulomatous diseases with an accuracy of 89%, as a result of increased glycose metabolism [24]. FDG-PET technique is simple as it can be performed with one injection, with quick results, but not as cost effective and widespread as 3-phase bone scan [24]. Accumulation of 18F-fluotake, is similar to Tc-99m-MDP but with better pharmacokinetic profile (faster and higher uptake), is based on bloodstream and bone remodelling and is preferred to diagnose musculoskeletal abnormalities. Standardized uptake value (SUV) can be used to quantify 18F-fluoride [25]. Scarce literature evidence exist about 18F-fluoride-PET scan of total

TABLE 1. Imaging modalities, appropriateness rating and relative radiation levels [4]

Imaging Technique	Main Indication	Radiation (Msv)
X-Rays	Rotine follow up	0.1-0.4
US	Superficial infection, abductor tendon	0
CT	Aseptic loosening, PPF	7-10
CT guided aspiration	Joint infection	2.7-5.3
MRI	Muscles, tendon, nerves, ALVAL, metal-on-metal complications	0
Tc-99m bone scan / Ga-67 scan	PJI	4.2
FDG-PET scan	PJI	21-25
WBC marrow scan	PJI	variable

US: Ultrasonography, CT: computed tomography, PPF: periprosthetic fracture, MRI: magnetic resonance imaging, ALVAL: Aseptic lymphocyte-dominant vasculitis-associated lesion, Tc-99m: Technetium-99m, Ga-67: Gallium 67, FDG-PET: fluorodeoxyglucose positron emission tomography, PJI: periprosthetic joint infection

hip arthroplasties. It could be used for diagnosis of avascular necrosis [26], for metabolic bone profile analysis and potential instability and for detection of infected arthroplasties [27].

Ultrasonography (US): This is a non – invasive way to evaluate soft tissues around hip arthroplasty, hematomas and fluid collections This technique is useful for imaging soft tissues around a hip prosthesis, including effusion, collection] and performing precise joint aspirations or biopsies [28].

Case-depending imaging evaluation

Case 1: Asymptomatic patient after total hip replacement

Postoperative radiographs are routinely used to detect early surgical complications (like dislocation, periprosthetic fracture and implant malposition), evaluate operation goals (implant positioning) and serve as baseline for patient's follow up [29, 30]. Follow up evaluation of an asymptomatic patient is usually done with radiographs to detect implant positioning and possible migration, osteointegration and heterotopic ossification [31] (Figure 1). Disadvantages of radiographic follow up is the limited sensitivity for detecting minor osteolysis and the possible cost-effectiveness [32]. Different radiographic follow up strategies are proposed and selected based on surgeon's preference: from no follow up, yearly follow up or a minimum follow up at 3 and 12 months. Patients with metal-on-metal hip arthroplasties should be scheduled yearly [33]. Routinely CT follow up evaluation of asymptomatic patients is not suggested, but it can be used at 5 to 7 years after the initial operation in young and active patients or in patients with hybrid implants [34]. CT scan can be performed for wear evaluation when asymptomatic radiographic lucencies are spotted.

MRI is not used for routinely evaluation of patients after THA due to high cost and patient's convenience. MRI findings in an asymptomatic patient can be reactive synovitis, without known clinical significance that can last for several months postoperatively [35]. Soft masses surrounding the implants are observed in up to 50% of patients 46 months postoperatively when MRI scans are conducted in patients with metal-on-metal THA [36]. Patients with metal-on-metal THA should be followed up yearly with radiographs and a soft tissue imaging modality of choice [30]. Metal ion levels on serum blood is not

Fig. 1. Standard radiographic evaluation for routine follow up of an asymptomatic patient after total hip arthroplasty.

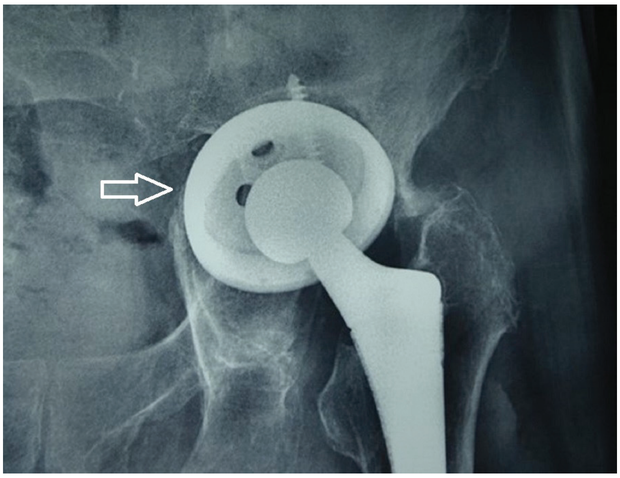

Fig. 2. Acetabular component malposition detected on x-rays. White arrow shows rotational implant migration.

recommended to be checked yearly, as soon as there is no functional problem or other complication [36].

Bone scan is not routinely recommended for THA follow up evaluation Scan images can detect post-operative complications and stress risers. Literature review suggest that that bone uptake decreases the months following the arthroplasty and that the maximum accumulation is noticed around the tip of the femoral stem [37]. Implant type and material used and presence of cement play a significant role in bone scan appearance [25]. WBC scan is performed mainly for academic reasons and not in routine basis. When performed, the main uptake is found around the tip of femoral prosthesis. Ultrasonography is not recommended for routine evaluation of asymptomatic total hip arthroplasties.

Case 2: Implant malposition evaluation after total hip replacement

AP and lateral x-rays are commonly used to routinely detect implant malposition, evaluate femoral offset and femoral stem-shaft angle [2] (Figure 2). Specialized imaging projections like modified Budin view for examining femoral anteversion can be also reliable, but is not used in the common practice [38]. Radiographic evaluation of acetabular component depends on patient positioning and the delineation of the reference plane. Several studies correlated radiographic and CT results for implant position evaluation, with similar and satisfying results, although CT scans offer measurement accuracy and better 3D view of the construct [10, 39]. Current belief though, is that CT scan can be more accurate than typical radiographs for evaluating and measuring precisely component anteversion or inclination [40].

Case 3: Evaluation of a painful total hip replacement

Periprosthetic joint infection is a serious and devastating complication counting for 1-2% in primary THA and around 5-6% in revision arthroplasties [41]. Identification of a single causative microorganism is not always possible and thorough evaluation with minor and major criteria is always needed [42]. Although, diagnosis of periprosthetic joint infection resides on clinical and laboratory findings, imaging evaluation is always helpful.

Radiographs on acute periprosthetic joint infections are usually normal. Even in chronic infections, x-rays can be normal and cannot exclude this diagnosis. Radiographic loosening around components along with clinical evaluation are suggestive of a

Fig. 3. *CT guided hip joint aspiration for the evaluation of a painful total hip replacement to rule out periprosthetic joint infection.*

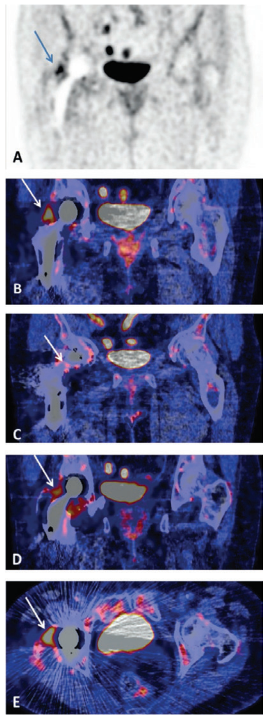

Fig. 4. *A normal non-infected total hip prosthesis with 18F-FDG uptake. (A) Coronal FDG-PET image with increased FDG uptake around the implant, mainly noted at the lateral side of the column; (B, C, D) Coronal fused FDG-PET/CT images at different slices with uptake around the prosthesis; (E) Trans axial fused FDG-PET/CT image with significant uptake at the lateral side of the acetabular cup [65].*

chronic periprosthetic infection [43]. Further investigation with CT scan of a painful THA has excellent specificity detecting reactive periosteal bone formation and fluid collections [44]. CT guided joint aspiration is extremely useful to confirm the aetiology of infection (Figure 3). Additional findings from CT scan of an infected THA are fluid collections, component loosening and migration [45]. MRI scans can further evaluate soft tissue condition around an infected THA. Common MRI findings are soft tissue edema, synovial sign intensity, joint effusion, fluid collections, fistulas, bone marrow edema and lymphadenopathy [8, 46].

The bone scan has high sensitivity but low specificity for the diagnosis of periprosthetic joint infection [47]. Even the use of a three-phase bone scan does not increase accuracy [28, 48]. A normal or negative bone scan has a high probability of ruling out infection or aseptic loosening [49, 50]. Bone scan should be accompanied with contrast agents such as gallium or labelled leukocyte [28]. Periprosthetic bone uptake patterns are not reliable for predicting loosening or infection [28]. Positive gallium bone scan indicates periprosthetic joint infection, but normal result could not rule out sepsis and needs further evaluation [28, 46, 50-51].

Chronic low grade periprosthetic joint infection can be associated with false negative results in WBC labelled bone scan [28]. Combination of 3-phase bone scan with WBC labelled scan is highly accurate and recommended for detecting periprosthetic infection [28]. WBC/marrow scan is an alternative imaging method with high specific (100%) and accurate (88%) imaging method [52].

The fluorodeoxyglucose - positron emission tomography (FDG-PET) scan is another imaging technique to visualize and measure metabolic changes and physiological parameters, using radioactive substances [28, 37, 53]. FDG-PET scan has high sensitivi-

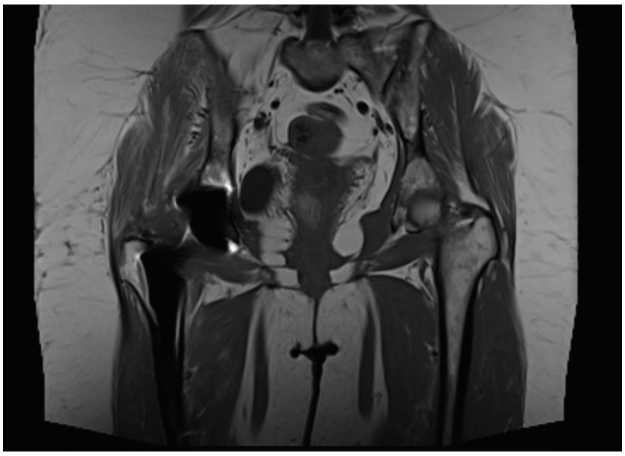

Fig. 5. *MRI evaluation of soft tissues (muscles, tendons and ligaments) around the hip after total hip arthroplasty*

ty and specificity (over 90% and that's more sensitive than WBC/marrow scan) and can diagnose septic from aseptic loosening [54]. Compared to 3-phase bone scan, FDG-PET is more specific and less sensitive [32, 55]. Location of uptake around the femoral stem and intensity of bone uptake during FDG-PET characterize periprosthetic infection [56].

Skeletal PET scan with 18F-fluoride PET is another option to diagnose bone lesions and septic loosening in symptomatic and asymptomatic patients [37]. Bone uptake and SUVmax (uptake>50% and SUVmax >5) is increased and significantly higher in infected cases [57]. The increased accuracy of 18F-fluoride PET can be used for screening health and infected tissues and it may play an important role in implant-retaining surgeries.

US scan can detect superficial infection, soft tissue edema or abscesses around the joint, but has limited value when examining low grade or deep layer infections [58]. When combined with arthrography could be useful.

Joint aspiration US or CT-guided is widely used for detecting any causative pathogen (sensitivity 40-93%, specificity 82-100% [59]. Antibiotics should be stopped for at least two weeks before aspiration. There is no clear guideline recommendation on the timing of joint aspiration, but should be strongly considered in every infection-suspected THA after clinical and laboratory consideration. Joint fluid could be sent for microbiological biochemical analysis to diagnose with a high positive likelihood ratio septic joint but not exclude infection [48]. Arthrography is not routinely performed, but can take place during joint aspiration and can add important information regarding fistulas and fluid collections.

Case 4: Aseptic loosening evaluation of a total hip replacement

Lucencies around the total hip arthroplasty are usually found with AP and plain radiographs, but their presence is not always easy [8]. Radiographs have sensitivity of 81% and specificity of 74% for detecting aseptic loosening of acetabular and femoral component [60]. Radiographic evaluation of aseptic loosening of THA remains the first choice in the diagnostic evaluation, offering accuracy and simplicity comparing with other diagnostic methods like arthrography [60].

CT scan can be used for better 3D visualization and evaluation of implant loosening [61]. MRI is not routinely used [61]. Bone scan can be used alongside radiographs for better interpretation when patient history and clinical findings are unclear [51]. When examining aseptic loosening around THA, bone scan alone has a sensitivity of 88% and specificity of 50% [60, 62].

Aseptic loosening could be diagnosed with nuclear or contrast arthrography (70% sensitivity, 100% specificity). Nuclear arthrography is slightly better compared with contrast arthrography [63]. Their combination of two offers much better results (over 90% sensitivity, specificity).

FDG-PET scan and uptake pattern can be used to diagnose septic from aseptic component loosening [27, 50, 64]. In aseptic loosening, main uptake is around the head and neck of the implant [55, 57] (Figure 4).

Arthrography is another well documented technique for diagnosing aseptic loosening with high sensitivity and specificity rates (96% and 92% respectively) when suspecting femoral component, and lower sensitivity and specificity rates (97% and 68%, respectively) when examining acetabular component. Nowadays, arthrography is not a first line choice for detecting component loosening [66].

Case 5: Evaluation of aggressive granulomatous disease

Aseptic loosening around arthroplasty components is a response to small particles like cement, polyethylene or other debris [67]. Another uncommon cause of aseptic loosening can be granulomatous disease that is often asymptomatic. Bone resorption around implants is often identified with radiographs (sensitivity 62%, specificity 100%), before further evaluation with CT is made to reveal even focal lesions [9, 10]. Modern scanning CT techniques can reveal up to 48% of silent osteolytic lesions, without clinical and radiological findings [68]. Metal artifacts are the main reason for not revealing minor bone defects [69]. MRI scan is the method of choice for detecting and measuring exact volume of granulomatous disease, with 95.4% sensitivity for large lesions >1cm^3 [21, 70]. Gadolinium injected agent can provoke granulomas enlargement [23]. FDG-PET scan with increased FDG uptake is also described for detecting aggressive granulomatous disease [70].

Case 6: Evaluation of painful metal-on-metal total hip arthroplasty or aseptic lymphocyte-dominated vasculitis-associated lesion. (ALVAL)

Metal wear debris and associated loosening have been reduced nowadays due to modern implants and surgical techniques for metal-on-metal arthroplasties [71]. Typical complications after metal-on-metal arthroplasties are initially metallosis and hypersensitivity reactions and finally pseudotumours or aseptic lymphocyte-dominated vasculitis-associated lesion (ALVAL) [72]. Metal ion levels have no correlation with wear rate or screening tools [73]. Histologically, ALVAL infiltrates vascular structures. Solid lesions are located anteriorly near or within psoas muscle and cystic lesions located posteriorly, involving the gluteal muscle [74].

Simple x-rays may reveal osteolysis or asymptomatic femoral neck thinning after surfacing arthroplasties, but ALVAL evaluation is not possible [75. Although metal artifact remains a problem, MRI is a valuable imaging technique to evaluate soft tissues, tendon, bone quality and neurovascular structures and diagnosing symptomatic or asymptomatic ALVAL [72, 74-77]. Pseudotumor symptoms are related to mass density and location of masses [76, 77]. Other MRI finding suggestive of ALVAL lesion are synovial thickness and masses [78-79]. MRI contrast agent is needed to diagnosis necrotic bone regions [71].

When MRI scan is not possible, US can diagnose superficial soft tissue masses, without metal artifacts [39, 68, 74]. High-resolution US has 74% sensitivity and 92% specificity in detecting local soft tissue masses and reactions after metal-on-metal THA [79].

Case 7: Trochanteric pain evaluation after primary total hip replacement

Differential diagnosis of trochanteric pain after THA consists of trochanteric bursitis or abductor muscle injury. AP and lateral x-rays are the first imaging modality used to exclude fractures around the trochanter and heterotopic bone formation. Radiographs can accidentally reveal surface abnormalities >2mm around the trochanter that can be correlated with abductor tendinopathy [80]. MRI scan is the method of choice to detect with accuracy abductor muscle pathophysiology, including tendon tears, ruptures or fatty atrophy [79]. Ultrasonography is an alternative method to examine and differentiate hip abductors abnormalities, such as tendon avulsions, abduction muscle laxity or offset problems [81]. When suspecting capsular defect, arthrography with contrast can detect tendon disruption to the trochanteric region. Abductor tendon pathology is not excluded with negative arthrography result [82].

Case 8: Iliopsoas bursitis or tendonitis after total hip replacement

Postoperative anterior groin pain is typically due to iliopsoas impingement, when acetabular implant is malpositioned, passing the anteromedial edge of the acetabulum [78]. Other common causes of impingement are excessive bone graft or cement, penetrating screws, antiprotrusio cage or reinforcement ring and osteophytes around the hip joint [79-84]. Injection of local anaesthetic on the pain site can be diagnostic for iliopsoas inflammation [85, 86]. Radiographic evaluation can be used for initial evaluation. Acetabular implant malposition with more than 12mm overextension can provoke iliopsoas impingement and can be assessed with lateral x-ray or CT scan [83]. Iliopsoas tendon morphology and pathophysiology can be studied extensively with MRI, especially when there are not metal implants. This kind of imaging can reveal tendinopathy, partial or full thickness rupture and bursitis [84] (Figure 5). When MRI scan is not available, US scan can be performed to demonstrate snapping of the tendon over the anterior edge of the acetabular implant [86].

Case 9: Nerve injury evaluation after total hip replacement
Nerve injuries count for around 1% of overall THA complications [87]. Peroneal division of sciatic nerve is the most frequent nerve injury after THA (80% of cases), followed by the inferior division of the superior gluteal nerve during posterior and direct lateral approach, respectively [88]. Main reasons for nerve palsy are poor surgical technique, malpositioned screws or implants, cement, heterotopic ossification, scar tissues, hematomas and postoperative fluid collections [89]. MRI has been the first line choice for detecting and evaluating nerve injuries around the hip, as it can give a precise and accurate soft tissue image even in obese patients, whereas US remains less favourable choice, as it can detect only superficial damages or non-obese patients [36, 90]. MRI has been used successfully to evaluate nerves around the hip, including the sciatic nerve [91].

Case 10: Heterotopic ossification evaluation after total hip replacement
Because of their simplicity and low cost, AP and lateral x-rays are the preferred approach for diagnosing and staging heterotopic ossification. Radiographs are used in the Brooker categorization system for heterotopic bone following total hip arthroplasty [61]. First ossified bone is visible in x-rays after 4-6 from the operation. One year postoperatively, bone formation gradually stops and is considered stable [92]. Symptomatic and stable heterotopic bone disease can be surgically removed. CT can be used preoperatively for volumetric evaluation of bone, whereas MRI can be useful for evaluation of soft tissues, nerves or vessels around the joint [21, 92]. High sensitive three-phase bone scanning can detect heterotopic ossification in an early stage, such as 2 weeks after the operation and determine bone maturity, although is not usually done in common practice [93]. Another imaging modality that can be used for early evaluation of bone ossification before radiographs is ultrasonography, with possible diagnosis a week after operation. It is user dependent modality that is more accurate when heterotopic bone formation is mature in serial examinations [94].

Case 11: Periprosthetic fracture evaluation after total hip replacement
First line of imaging evaluation of suspected periprosthetic fracture consists of AP and plain radiographs. CT is more helpful when assessing acetabular bone fractures, often used for better evaluation of remaining bone stock and preoperative planning. MRI has a higher accuracy than radiographs or CT and can be used in more obscure cases to diagnose stress reactions or nondisplaced fractures [8].

Conclusion
Because of the growing number of hip replacements performed worldwide, imaging screening following total hip arthroplasty remains a common clinical topic for any participating clinician. There are several imaging modalities available today for the appropriate clinical need. For the initial imaging examination following total hip arthroplasty, radiographs remain the gold standard. Depending on the patient's situation, other imaging modalities may be performed. When CT and MRI scans are required, they are frequently the second choice. CT scans are a good way to assess bone stock, aseptic loosening of the acetabular component, and periprosthetic fractures. MRI is useful when assessing soft tissues, muscles, nerves around the hip joint or granulomatous disease. Bone scan is a useful technique that remains still valuable in clinical practice. CT-guided aspiration of hip joint is recommended to diagnose periprosthetic joint infection. WBC/marrow scan can be used additionally when sepsis is suspected. Injection of anaesthetic or corticosteroid substances can be used in doctor's office for differential diagnosis of iliopsoas impingement. Patient history, physical examination and intraoperative findings should be considered. Collaboration between orthopaedic

surgeon and radiologist is crucial for the right imaging evaluation of a patient undergoing total hip arthroplasty. **R**

Compliance with Ethical Standards

Conflict of interest

The authors declare that they have no conflict of interest.

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Not applicable.

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