Knee & Shoulder Arthroscopy And Arthroplasty
ISKSAA

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Journal of Arthroscopy and Joint Surgery

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Managing Editor,
Journal of Arthroscopy and Joint Surgery,
Center for Arthroscopy, Sports Medicine and
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Email: isksaaeducation@gmail.com

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Contents


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Why a Radiology Special Issue? And About the Guest Editors…

As the editors-in-chief of this journal, we would like to take this opportunity to recognize and acknowledge the invaluable contributions of the guest editors and the musculoskeletal radiologists to this issue.

Musculoskeletal radiology plays a critical role in the diagnosis and management of a wide range of orthopedic conditions, from fractures and sports injuries to degenerative joint disease, infection, and complex orthopedic tumors. This specialty is like the eye through which orthopedic surgeons see the pathologies to make a diagnosis and address the patients' problems.

The expertise and knowledge of musculoskeletal radiologists have been instrumental in advancing the fields of arthroscopy and arthroplasty and improving patient outcomes. They work closely with orthopedic surgeons to develop comprehensive treatment plans that are tailored to the patient's needs and provide critical information on the location and extent of the pathology, which helps us to plan treatment strategies.

In this special issue, we are proud to publish the latest research and advancements in the field of musculoskeletal radiology, with a particular focus on arthroscopy, sports medicine, and arthroplasty. We recognize the need for an issue since sports surgeons routinely perform ultrasound-guided injections and procedures and arthroplasty surgeons, closely work with radiologists in various conditions and would benefit from this issue. There are articles on key advances in the imaging modalities in sports injuries as well as arthroplasty including guides to perform image-guided procedures.

This editorial would be incomplete without acknowledging the guest editors who are well-known and published doctors in their own right. They have been working hard from framing the list of articles, selecting the authors, reviewing the articles, and editing them before submitting to us.

Dr. Sanjay Patel is the lead guest editor who is currently a consultant musculoskeletal radiologist at I-MED Radiology Networks, Brisbane, Australia. Following on from completing basic surgical training and surgical rotations in the UK, Dr. Patel completed MRCS. He then worked as a surgical trainee in orthopedics and neurosurgery. After obtaining broad surgical knowledge, he entered radiology training at Norwich Radiology Academy and received CCST and FRCR. He then worked as a consultant radiologist with specialist interests in musculoskeletal and neuroradiology at Royal Derby Hospital, UK.

Dr. Patel is the author of several published articles and presented in many national and international meetings. He published a book as a co-author with McGraw-Hills Radiology Case Review Series-Musculoskeletal Imaging. He is currently an editor for multiple international journals.

He is passionate about neuro, sports, and MSK radiology and his expertise has seen him consult at a national level, as well as supporting athletes including touring international cricket teams. He also performs image-guided injections and biopsies.

Dr. Patel was assisted by the duo of Dr. Rajesh Botchu, a consultant musculoskeletal radiologist at Royal Orthopaedic Hospital NHS Foundation Trust, Birmingham, UK, and Mr. Karthikeyan Iyengar, a Trauma and Orthopaedic surgeon from Southport and Ormskirk NHS Trust, Southport, UK. Both Dr. Botchu and Mr. Iyengar have a track record of extensively publishing in the field of musculoskeletal radiology and orthopedics.

Dr. Rajesh Botchu completed his radiology training from Leicester and subspecialty musculoskeletal training from ROH, Birmingham, NOC, Oxford and CIM, Geneva, Switzerland. He was awarded the clinician of the year in 2020. He regularly lectures at regional, national, and international meetings. He has a strong research portfolio with over 235 publications. Several signs are named after him including AamerBotchu sign, Iyengar-Botchu confluence, and Haleem-Botchu classification. He is a member of several musculoskeletal radiology societies. He is a cofounder of free teaching MSK Radiology4U app and website.

Mr. (Prof). Karthikeyan P. Iyengar works as a trauma and orthopedic surgeon at the Southport and Ormskirk NHS Trust with a special interest in orthopedic trauma. He has been conferred the title of Honorary Professor at Apollo Hospitals Educational and Research Foundation (AHERF) for his contribution to global teaching, training in Medical Education and Research Scholarship. He has a prominent global research profile; being on the list that represents the top 2% of scientists in orthopedic surgery in the world released by Stanford University (USA) based on several citation metrics included in Scopus author profiles. He has a strong publication portfolio being an author of 150+ indexed, peer-reviewed articles, and chapters. He is a Deputy Editor at the Journal of Clinical Orthopaedics and Trauma and an Associate Editor at the Journal of Orthopaedics, Elsevier Journals, and supports academic mentorship in scientific publications.

The speciality articles will be split between two of our regular issues with four articles published in the first issue along with two editorials and two of our regular articles and the rest six articles published in the next issue. We would like to wholeheartedly thank the guest editors for their efforts and contributions in bringing out this special issue in time. We would also like to thank the contributing authors to his issue for their manuscripts.

We are confident that this issue would be useful to practicing sports and arthroscopy surgeons as well as arthroplasty surgeons in matters related to musculoskeletal radiology.

Srinivas B. S. Kambhampati, Hemant Pandit[1], Amol Tambe[2]

Department of Orthopaedics, SKDGOC, Vijayawada, Andhra Pradesh, India, [1]Department of Orthopaedics, LIRMM University of Leeds, Chapel Allerton Hospital, Leeds, [2]Department of Orthopaedics, Royal Derby Hospital, Derby, England, UK

Address for correspondence: Dr. Srinivas B. S. Kambhampati, “Sri Dhaatri”, 23, Lane 2, SKDGOC, Vijayawada - 520 008, Andhra Pradesh, India.
E-mail: kbssrinivas@gmail.com

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Guest Editors

Sanjay Patel, Karthikeyan P. Iyengar[1], Rajesh Botchu[2]
I-MED Radiology Network, Forest Lake Boulevard, Forest Lake, Brisbane, Australia, [1]Honorary Professor, Apollo Hospitals Educational and Research Foundation (AHERF), Department of Orthopedics, Southport and Ormskirk NHS Trust, Southport, [2]Department of Musucloskeletal Radiology, Royal Orthopedic Hospital, Birmingham, UK

Address for correspondence: Dr. Sanjay Patel, I-MED Radiology Network, 255 Forest Lake Boulevard, Forest Lake, Brisbane, QLD 4078, Australia.
E-mail: sanjaybrisbane@gmail.com

Musculoskeletal radiology is an integral component in the diagnosis and management of orthopedic conditions. A range of imaging modalities are available including radiographs, ultrasound, magnetic resonance imaging (MRI), computed tomography, and nuclear medicine. Using appropriate imaging tool to confirm and support clinical findings is crucial to target appropriate patient management and reduce morbidity. In this special issue on musculoskeletal radiology, we have included several articles on a spectrum of musculoskeletal pathologies written by experts from across the globe. Review articles on intraoperative imaging, extended role of ultrasound imaging, and advances in sports imaging from experts are worth reading as it covers the entire spectrum of imaging modalities applied in managing orthopedic pathologies with important key messages. An article on advantages and disadvantages of the strength of MRI with a bird's-eye view about ultra-high field MRI is worth mentioning. It is common to see incidental lesions on imaging. These can be seen while imaging sports professionals too. One of the articles in this issue describes the authors' experiences of "incidentalomas" that they have encountered during the imaging of sports professionals. Increasingly, radiological imaging is required in intraoperative fixation of orthopedic trauma and interventions. This has been highlighted in the role of intraoperative imaging article. Bone tumors are rare, but early diagnosis is essential to decrease morbidity and mortality. An article on imaging of bone tumors provides a bird's-eye view that should be useful for readers.

We hope that these would be of interest to the researchers and clinicians, in particular the readers of JAJS. We would like to thank the contributors, reviewers, and editorial board, who have collaborated effectively to make this issue a success.

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Hip and Knee Arthroplasty: A Review of Complications and Advances in Imaging

Elise Chua[1,2], Dhiren Shah[1]

[1]Department of Radiology, London North West University Healthcare NHS Trust, [2]Department of Radiology, The Royal National Orthopaedic Hospital NHS Trust, London, UK

Abstract

Arthroplasty-related complications are challenging to diagnose as they often present with nonspecific signs and symptoms, and can lead to long-term morbidity if inadequately managed. The difficulty in imaging implants is compounded by its intrinsic propensity to artifacts. Strategies to reduce this include: Judicious use of the appropriate imaging modality for the relevant clinical indication; knowledge of optimizing imaging acquisition parameters; and use of metal artifact reduction (MAR) software. We review the literature on expected normal appearances of hip and knee arthroplasties, findings of arthroplasty-related complications on various imaging modalities, advances in imaging techniques, and subsequently, suggest an algorithm for painful arthroplasty assessment. Serial radiographs remain key in identifying subtle changes in component position, hardware failure, periprosthetic osteolysis, and potential for loosening, given their ready availability, high resolution, and minimal metal-related artifact. Computed tomography with MAR provides 3D assessment and information on bone stock for surgical planning and custom implants. Magnetic resonance imaging with MAR can identify complications at earlier stages, such as loosening, capsular dehiscence in instability, and periprosthetic edema in nondisplaced fractures. It has high diagnostic performance in infection (lamellated synovitis), particle disease, adverse reactions to metal debris, in addition to demonstrating impingement on neurovascular structures. Nuclear medicine imaging is used as a problem-solving tool and is valuable in its high negative predictive value. Novel imaging techniques can further reduce artifacts and improve visualization of the implant-bone interface, and machine learning can facilitate image interpretation although attaining sufficient data and clinical validation will be challenging.

Keywords: Hip arthroplasty, imaging, knee arthroplasty, magnetic resonance imaging

Introduction

Although the incidence of arthroplasty-related complications is low, particularly with improved implant components and surgical techniques, the prevalence of arthroplasties is increasing due to an aging population. The range of complications often presents with vague signs and symptoms, hence knowledge of the diagnostic imaging options is important to guide management and revision.

In this review, we present the expected normal appearances of hip and knee arthroplasties on various modalities, common modes of implant failure, and an algorithm for painful arthroplasty assessment. We discuss the importance of the multidisciplinary team (MDT), advances in imaging modalities, and artificial intelligence.

Methods

A literature search was performed on the PubMed database using the search parameters: "hip arthroplasty" (or "total hip arthroplasty [THA]" or "total hip replacement" or "hip replacement") or "knee arthroplasty" (or "total knee arthroplasty [TKA]" or "total knee replacement" or "knee replacement"), and imaging (or "radiographic" or "MRI" or "nuclear medicine") or advanced imaging (or "metal artifact reduction" or "advanced MRI" or "multiacquisition with variable-resonance image combination [MAVRIC])" or "slice encoding for metal artifact correction [SEMAC]") for data on imaging of arthroplasty-related complications. The search parameters "arthroplasty" (or "joint replacement") and "artificial intelligence" (or "machine learning" or "deep learning") were used for information on artificial intelligence

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Address for correspondence: Dr. Elise Chua, 11B, Barton Road, London, W14 9HB, UK. E-mail: eliseychua@gmail.com

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in arthroplasty imaging. We only evaluated studies published in peer-reviewed journals in English. Abstracts were screened, potentially relevant studies identified, and full texts retrieved. Qualitative descriptions of imaging findings and quantitative diagnostic accuracy scores were compared. The American Joint Replacement Registry was utilized for up-to-date arthroplasty revision data.

Discussion

Risk factors

The rate and type of complications following arthroplasty depend on patient factors, surgical approach, and implant configuration. Knowledge of these risk factors is crucial in guiding choice of imaging modality and image interpretation.

Patient factors such as age, obesity, diabetes, inflammatory arthritis, and immunosuppression result in slower recovery and higher infection risk.[1] Suboptimal component alignment, imbalanced muscle atrophy, extent of dissection, ease of capsule repair, and a posterior approach[2] in THA (although this has been more recently debated)[3-5] increase the risk of dislocation.

Osteoporosis, trauma, osteolysis, loosening, previous fracture, noncemented and longer implant stems are risk factors for subsidence and periprosthetic fracture.[6,7] Other implant factors such as the type of bearing surfaces and modular junctions of implant stems, incomplete cementation, and inadequate ligamentous balancing have implications on wear and loosening.[8] Constrained TKAs, for example, exert more force on bone than ligaments, increasing rates of wear-related disease.[9]

Normal imaging surveillance and findings

As radiographs are readily available, have high resolution and minimal metal-related artifacts, they are critical for baseline and surveillance imaging and provide an overview of component positioning and alignment.

Alignment of a THA can be evaluated on standing anteroposterior (AP) radiograph by measurement of a leg-length discrepancy, centers of rotation, lateral acetabular inclination, and femoral stem position [Figure 1a].[10] For TKA, the mechanical axis from the center of the femoral head to the center of the talar dome on the standing radiograph should pass through the center (or slightly medial) of the implant [Figure 1b]. Valgus angle between mechanical axis and femoral axis (along the femoral shaft) should be 4°–7°.[11]

Thin radiolucency (<2 mm) along a cemented prosthesis within the first 6 months or noncemented prosthesis within the first few years reflect incomplete interface contact.[12,13] This is considered normal if stable and thus serial radiographs are essential. Stress shielding can be seen within the first 2 years, typically at the superomedial acetabulum and medial proximal femur in THA,[10,14] and adjacent to the anterior femoral flange or tibial tray in TKA.[11]

In noncemented femoral stems, subsidence (change in distance from greater trochanter to the lateral shoulder of femoral component) of <10 mm within in the 1st year[13] and osseous proliferation at the femoral stem junction ("spot weld")[10] are also within normal limits.

Computed tomography (CT) is useful for 3D assessment of hardware and bone stock, although periprosthetic detail is limited by beam hardening and streak artifact. Nuclear medicine imaging provides functional information and is recommended by the American College of Radiology appropriateness criteria if other modalities are negative.[15]

Magnetic resonance imaging (MRI) has superior marrow and soft tissue contrast and is increasingly used with advances in metal artifact reduction sequences (MARS). It can be utilized immediately if there are no ferromagnetic components, or else as early as 6–8 weeks. Synovitis, edema, and fluid around the implant are normal in the immediate postoperative period.[16] The pseudocapsule then appears as a thin hypointense rim on fluid-sensitive sequences.[17] The marrow cavity appears hyperintense secondary to surgical preparation with reaming and bone compaction. This may be seen for more than a year but can be distinguished from a stress reaction by implantation date and lack of ancillary features such as periostitis.[18]

Complications

From 2012 to 2021, the American Joint Replacement Registry 2022 reported the most common reasons for hip revision were infection (21.2%), instability (18.3%), and loosening (16.3%). The most common reasons for knee revision were infection (28.4%) and loosening (24%).[19]

Malpositioning

Hardware malalignment or malrotation contributes to limited range of motion, pain, eccentric wear, instability, dislocation, and reduce implant survival.[20,21] Measurements are primarily performed on radiographs, with CT reserved for when more precise reconstructions are required.

Park *et al*. found a method by Liaw *et al*. using AP radiographs to be the most accurate at measuring acetabular component anteversion after THA.[22] Femoral stem anteversion is preferably assessed on CT due to variation in pelvic and thigh rotation, and using the transepicondylar axis as a distal reference has been shown to achieve better inter/intra-observer agreement.[23] The recommended combined anteversion is 25°–50°.[23]

The measurement of the femoral component is highly reproducible on CT. Various methods for measurement of tibial component rotation have been proposed such as the Berger protocol utilizing axial CT [Figure 1b].[24] The posterior condylar angle between the surgical transepicondylar axis (STA; from sulcus of the medial epicondyle to prominence of the lateral epicondyle) and posterior condylar line (PCL; along posterior margins of the condyles) indicates femoral component rotation [Figure 1c]. A line along the posterior surface of the tibial component polyethylene (PST) [Figure 1d] and geometric center (GC) of the tibial plateau [Figure 1e]

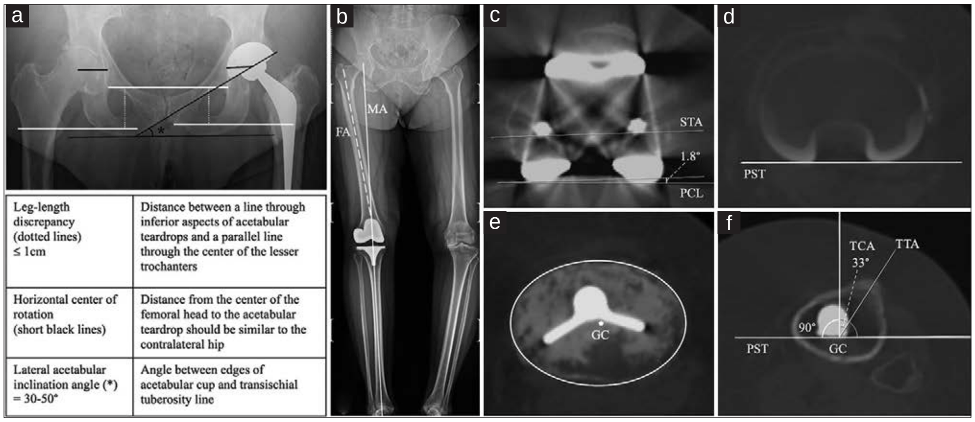

Figure 1: Standing radiographs illustrating hip (a) and knee (b) arthroplasty alignment. Valgus angle is measured between the MA and FA axes. (c-f) Berger protocol for knee arthroplasty rotation on axial CT. STA: Surgical transepicondylar axis, PCL: Posterior condylar line, PST: Posterior surface of tibial polyethylene, GC: Geometric centre, TTA: Tibial tuberosity axis, TCA: Tibial component axis, MA: Mechanical, FA: Femoral, CT: Computed tomography

is transposed to an axial slice through the tibial tuberosity prominence [Figure 1f]. The angle between a line perpendicular to the PST and a line from the GC to tibial tuberosity (tibial tuberosity axis [TTA]) is the tibial component axis (TCA), which indicates tibial component rotation. The tibial component is neutral when internally rotated 18° in relation to the tibial tuberosity tip. In the case example [Figure 1c-f], the externally rotated femoral component of 1.8° and internally rotated tibial component of 15°(33-18=15) would give a combined component internal rotation of 13.2°, which is higher than the accepted limit of 8.7°.

The Mayo protocol is reported to be superior but requires dedicated software.[25] A technique using the center of tibial tray to tibial tubercle distance has been proposed as a faster screening tool with good correlation to the Mayo protocol.[26]

Instability and dislocation

Dislocations are uncommon, with most occurring in the early postoperative period on initiation of weight-bearing due to pseudocapsule immaturity in the direction of surgical approach.[7] Subacute or late dislocation may be related to component malpositioning.[2] This is usually readily apparent on radiographs.

Diagnosis of instability is more challenging. In THA, fluid signal intensity (SI) between the external rotator tendons and the greater trochanter on MRI indicates posterior capsular dehiscence and instability.[27] Thickening and hyperintensity of the anterior capsule may indicate anterior instability, as this is usually due to excessive acetabular anteversion and femoral neck impingement on the posterior acetabular rim.[28]

Stress radiograph views can be useful in TKA. MR allows the evaluation of posteromedial and posterolateral stabilizers critical in mediolateral stability, as well as the extensor mechanism which contributes to posterior instability.[9]

Periprosthetic fracture

Displaced fractures can be easily detected on radiographs, which also provide information on implant stability to help determine management (utilizing the Vancouver classification system). Nondisplaced fractures may be radiographically occult, especially around the acetabulum [Figure 2]. CT with MAR is useful in such cases and better delineates fracture patterns.

MRI is particularly helpful in osteopenic patients where fracture visualization is challenging on CT, showing bone marrow edema, hypointense fracture line, periosteal reaction, and adjacent soft-tissue edema.[29] Findings may be subtle, especially in sites prone to susceptibility artifacts and therefore awareness of typical periprosthetic susceptibility artifacts is crucial. Single-photon emission CT (SPECT)-CT is useful in complex cases as it combines anatomical information with information on fracture age, stability, and union.[30]

Aseptic loosening

Mechanisms include fibrous or synovial-like membrane formation at the implant-bone or cement-bone interface and progressive loss of fixation, poor osseous integration (in non-cemented implants), or circumferential osteolysis due to wear-related disease.[31]

Serial radiographs can predict acetabular and femoral component loosening in 69% and 84%, respectively.[9] Loosening should be considered if there is periprosthetic lucency of <2 mm developing or progressing 2 years' postsurgery [Figure 3], but a diagnosis can be made if there is component migration or cement mantle fracture.[32] Osteolysis surrounding more than 50% of the cement mantle is also indicative, although the wear-related resorption appears lobular.[16]

In cemented acetabular components, lucency in all three DeLee and Charnley acetabular zones is highly diagnostic (94%).[33] In cemented femoral stems, lucency in Gruen zones three and five are the most significant signs of early loosening.[10] This is more challenging in non-cemented femoral stems as the component does not entirely fill the medullary canal, however developing or progressing subsidence more than 2 mm 2 years after surgery, or endosteal scalloping suggests loosening.[10] In

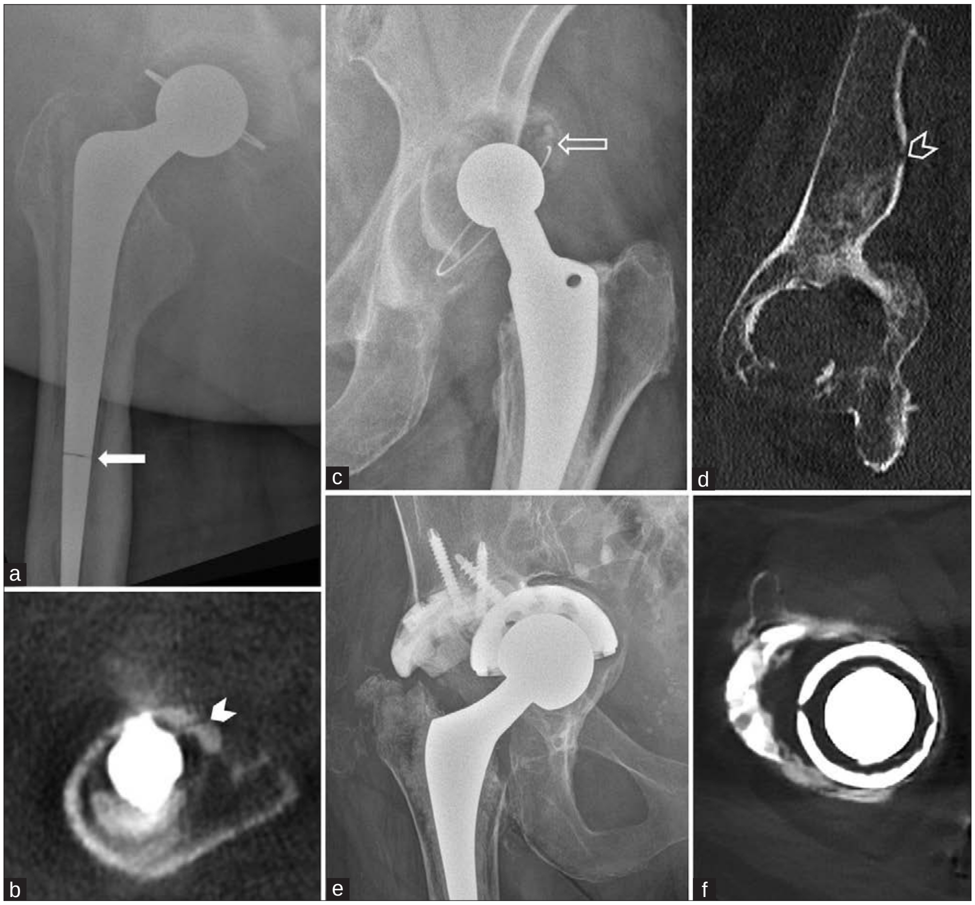

Figure 2: Hardware complications. (a and b) A nondisplaced femoral stem fracture (arrow) is well seen on radiograph due to minimal metal artifact, but MAR-CT better delineates the degree of osteolysis and identified a nondisplaced periprosthetic fracture (arrowhead). (c and d) An acetabular component fracture (void arrow) and subluxation can be seen on radiographs, but an associated fracture of the acetabular roof and ilium (void arrowhead) is better seen on MAR-CT. (e and f) Radiograph shows migration of the acetabular component and femoral head into the pelvis, with negative acetabular cup inclination. Insufficient bone stock around the acetabular component is better demonstrated on MAR-CT and indicates custom implant planning is required. MAR-CT: Metal artifact reduction-computed tomography

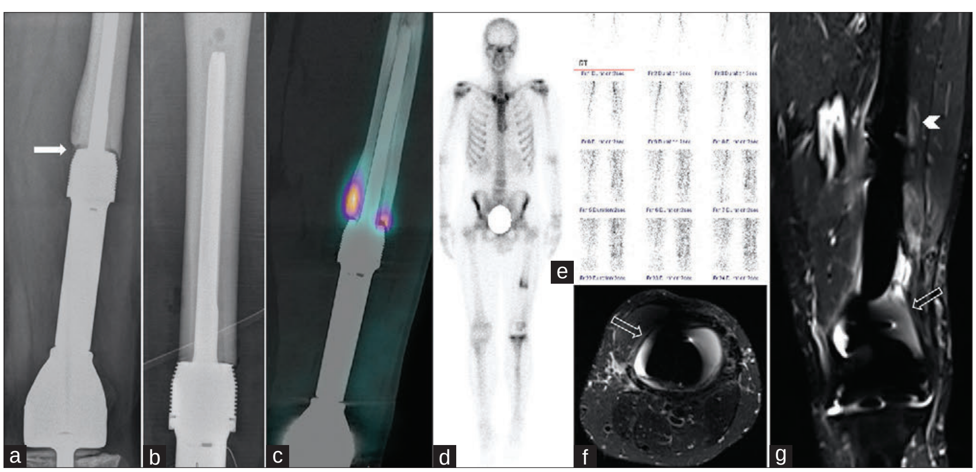

Figure 3: Painful distal femoral replacement in a 21-year-old man. Radiographs show a thin lucency (arrow) at the bone-prosthesis interface (a), new compared to 2 years prior (b). Technetium-99m hydroxydiphosphonate SPECT-CT (c) and bone scintigraphy (d and e) demonstrate corresponding triple phase uptake with osteolysis. Axial (f) and coronal (g) T2STIR MARS-MRI showed a suprapatellar effusion (void arrows) and soft tissue edema (arrowhead) at the bone-prosthesis interface. Appearances could represent periprosthetic infection, however as two separate aspirations and synovial biopsies were sterile, a diagnosis of aseptic loosening was made. SPECT-CT: Single-photon emission computed tomography-computed tomography, MARS-MRI: Metal artifact reduction sequences-magnetic resonance imaging

TKA, loosening should be suspected when there is a varus tilt of the tibial component of more than 5°.[34]

CT is useful if there is a high clinical suspicion despite normal radiographs, especially around the convex acetabular component which is poorly evaluated on radiographs and suffers from greater susceptibility artifact on MRI.[17] CT also provides detailed information on the degree of osteolysis and bone stock, important for surgical planning. A study reported tomosynthesis with MAR has benefits of reducing overlapping structures whilst minimizing artifacts and achieving better diagnostic accuracy than radiographs and CT in noncemented THR.[35]

MRI findings parallel those of other modalities; thin smooth intermediate or high SI at the bone and implant/cement interface represents fibrous membrane formation, but irregular or circumferential intermediate or high SI suggests loosening.[16,29] SPECT-CT and MRI have similar diagnostic accuracies,[36] but SPECT-CT may be utilized in difficult or equivocal cases owing to its high negative predictive value [Figure 3].[30]

As loosening cannot be diagnosed without excluding infection and wear-related synovitis, terms such as linear bone resorption may hence be used in imaging reports.

Periprosthetic infection

Imaging plays a particularly important role in patients with chronic indolent infections where clinical manifestations are subtle and inflammatory markers are nonspecific.

Radiographs have low sensitivity and specificity for infection. Osteolysis and periosteal reaction are only seen in advanced stages and overlap with findings in loosening and particle disease.[29] Features highly suspicious for infection include rapidly progressive or irregular osteolysis, or migration of more than 2 mm in 6–12 months.[37]

In addition to osseous findings, CT with MAR can detect joint effusions, enhancing thick-walled collections, and fistulae or sinus tracts, significantly increasing sensitivity and specificity to 100% and 87%, respectively.[38]

Bone scintigraphy has excellent sensitivity (90%–100%) for infection, even in early stages, but has poor specificity (35%).[38] In addition, periprosthetic uptake can be normal in the first 2 years following surgery.[38] Its utility is hence mainly in its excellent negative predictive value. Specificity is improved with the addition of white blood cell or anti-granulocyte antibodies scintigraphy but this may not be readily available.[39] SPECT-CT also improves diagnostic accuracy and localization of infection.[40]

MRI demonstrates high diagnostic performance in infection, achieving 94% sensitivity and 97% specificity in THA, and 92% sensitivity and 99% specificity in the knee, with European societies, now including MARS-MRI in consensus guidelines for periprosthetic infection work-up.[40] Lamellated synovitis (thick and hyperintense synovium comprised of multiple layers) is highly specific for infection and can be distinguished on MRI simple synovitis (homogenous SI) and particle-induced synovitis (hypertrophied synovium with a frond-like appearance).[41] Other signs such as complex joint effusion, extracapsular edema, regional lymphadenopathy, peripherally enhancing fluid collections which communicate with the implant, and sinus tracts between pseudocapsule or implant and skin surface have specificities of >90% [Figure 4].[42,43] Periprosthetic marrow edema, osteolysis, and decompression of capsular fluid into juxta-articular soft tissues have poor accuracies.[42,43]

Image-guided synovial fluid aspiration and tissue biopsy are performed, typically with ultrasound, to obtain samples for leukocyte count and microbiological culture.

Hardware complications

Component failure is rare but can lead to prosthetic displacement, fracture and lead to dislocation [Figure 2].[2] Supplementary fixators can also migrate, including cerclage wires or screws, and impinge adjacent tendons or neurovascular structure. Radiographs are often sufficient due to their high spatial resolution and little metal artifact.

Particle disease

Arthroplasty debris secondary to wear can result in a granulomatous reaction called particle disease. This may be due to polyethylene (>70%), cement, or metal and can cause geographic osteolysis, synovitis, and accelerate loosening.[16]

MRI is the most sensitivity modality for diagnosis of osteolysis (95%) compared to CT (75%) and radiographs (52%), although CT is typically used to evaluate the extent of bone loss before considering revision [Figure 5].[44]

On MRI, polyethylene wear-related osteolysis typically appears bulky and contains particulate debris isointense to skeletal muscle with a well-defined sclerotic hypointense rim.[17] Extra-articular soft tissue extension may mimic pseudotumors. Polyethylene wear-induced synovitis appears as synovial thickening and fronding with low to intermediate SI debris and fluid.[7] This can decompress through a dehiscent pseudocapsule and impinge ligamentous or neurovascular structures, which can be delineated on MRI.[17]

In THR, polyethylene liner wear at the weight-bearing portion of the acetabular component is a well-recognized complication that can cause component failure. Liner thinning and subsequent eccentric positioning of the femoral head may be subtle but can be detected on serial radiographs [Figure 5].

In TKR, femoral and tibial components not placed perpendicular to the mechanical axis increase the risk of polyethylene wear. It can be identified as joint asymmetry on AP radiographs, occasionally with associated osteolysis.[9]

Adverse reactions to metal debris

Adverse reactions to metal debris (ARMD) includes the spectrum of metal-related reactions, most commonly in metal-on-metal (MoM) THA, although it can be seen in non-MoM arthroplasties due cobalt alloy debris from modular femoral head-neck or neck-stem junctions.[45] ARMD can be

Figure 4: Increasing leg pain and swelling in a 56-year-old man with femoral and tibial replacements. Radiographs show soft tissue swelling and migrated screws (arrow) (a), but no change in osseous findings compared to 3 years prior (b). Coronal (c) and axial (d and e) T2STIR MARS-MRI showed lamellated synovitis (void arrowheads), joint effusion, pseudocapsule edema (arrowhead) and a sinus tract (void arrows) between pseudocapsule and skin highly suggestive of periprosthetic joint infection. *Staphylococcus aureus* was cultured from subsequent joint aspiration. MARS-MRI: Metal artifact reduction sequences-magnetic resonance imaging

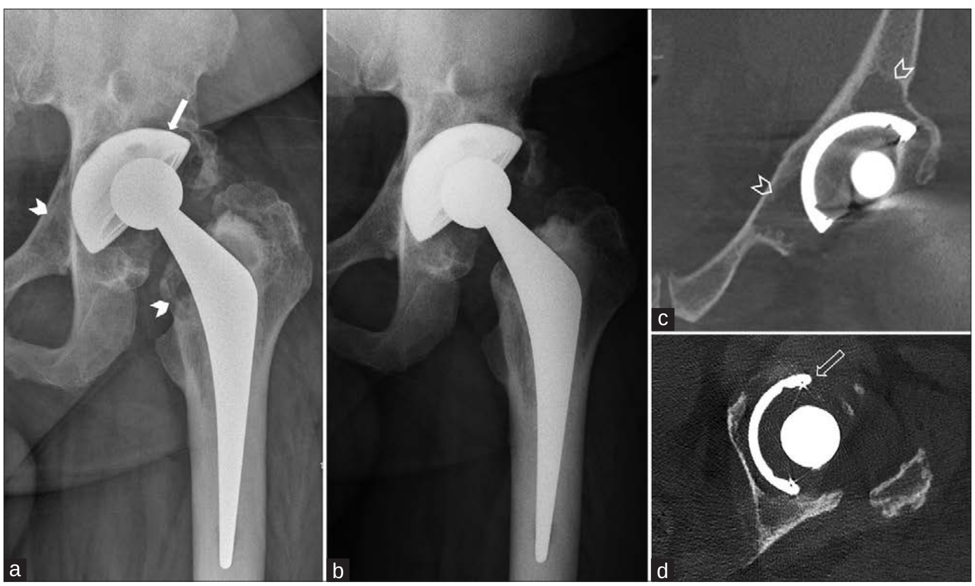

Figure 5: Left hip pain in a 61-year-old man. The radiograph shows the eccentric position of the femoral head (arrow), in keeping with acetabular liner wear, and osteolysis around the acetabulum and femoral stem (arrowheads) (a). This is particularly evident compared to radiograph 10 years prior (b). Coronal (c) and axial (d) MAR-CT more accurately delineates the significant osteolysis (void arrowheads) and acetabular cup retroversion (void arrow) in keeping with particle disease with loosening. MAR-CT: Metal artifact reduction-computed tomography

due to excessive wear of bearing surfaces resulting in the deposition of metallic debris in periprosthetic soft tissues, or hypersensitivity reaction to metal debris (without significant wear).[29]

Metallosis refers to the staining of synovium by metallic particles, while aseptic lymphocytic vasculitis associated lesion (ALVAL) refers to the histologic appearance of ARMD with hypersensitivity reaction and can cause rapid periprosthetic soft-tissue destruction. Pseudotumor is a non-neoplastic periprosthetic mass which can be seen along the spectrum of ARMD.

Serum cobalt and chromium ion levels are useful adjuncts but do not exclude ARMD if normal.[46] Radiographs may be normal or show dense effusions or periprosthetic soft-tissue masses.

MARS-MRI is the most comprehensive modality for ARMD, achieving a sensitivity of 94% and a specificity of 87%.[17] Metallosis is seen as hypointense foci within the synovium and regional lymph nodes with features of magnetic susceptibility.[29] Features of ALVAL range from hyperintense fluid within a thin distended pseudocapsule to solid synovial proliferation and debris.[29] Synovial thickening is a key sign in ARMD, particularly of an aggressive ALVAL-dominant reaction, and correlates with severity and corrosion damage.[47]

Pseudotumors can be easily identified on MARS-MRI and classified into three types based on wall thickness and if they are cystic or solid [Figure 6]. Symptom severity and revision rates increase from type I to type III.[48] Although symptoms do not correlate well with pseudotumor size,[49] MRI can identify associated marrow edema and tendon injury which contribute to symptoms.

Role of the multidisciplinary team

Arthroplasty complications are particularly challenging to manage due to the potential for long-term patient morbidity. The requirements for custom approaches to revision surgery, based on patient anatomy and implant type necessitate a careful interdisciplinary approach to any management, involving orthopedic surgeons, radiologists, plastic surgeons, microbiologists, pathologists, and physiotherapists.

MDTs are well established in several clinical settings including general oncology, sarcoma, trauma,[50] and diabetic foot infections. In the context of arthroplasty, imaging findings may herald implant failure, but in the absence of supportive clinical, serological, and microbiological evidence, do not necessarily warrant surgical treatment. Even when infection is suspected, the decision to aspirate requires consultation with radiologists for approach, often utilizing ultrasound, which is operator dependent.[51]

Qualitative analysis of a prosthetic knee infection MDT was found to improve communication, standardization of care and treatment pathways, and potentially cost-effectiveness.[52] Treatment plans such as antibiotic regimens, early revision surgery, and challenging decisions such as amputation where other options are exhausted should be made with MDT input to maximize patient outcomes.

Advanced imaging

Computed tomography

MAR software is widely used and corrects scatter and photon starvation by interpolating adjacent projections and uses iterative or model-based reconstructions.[53] Dual-energy CT

Figure 6: Increasing right hip pain in a 57-year-old man. Initial radiograph showed periprosthetic osteolysis (arrows) (a). Coronal MARS-MRI demonstrated a hypointense T1 (b) and hyperintense T2STIR (c) solid-cystic hip collection, with hypointense rim (arrowheads) indicating susceptibility artifact from the synovial metal debris. No significant change on radiograph a year later (d), but coronal T2STIR MARS-MRI (e and f) showed the collection increased in size and was more cystic with surrounding edema (void arrowhead) and regional lymphadenopathy (void arrow). Appearances were consistent with pseudotumor complicated by infection and cultures revealed Cutibacterium infection. MARS-MRI: Metal artifact reduction sequences-magnetic resonance imaging

with virtual monochromatic extrapolation further reduces beam hardening artifacts, allows assessment of different tissue types at individually optimal energy levels, achieving better contrast resolution of implants and adjacent tissues.[53]

Magnetic resonance imaging

The modification of MRI scanning parameters is required to limit metal susceptibility artifact, such as using a higher readout bandwidth, thinner sections, inversion recovery, and Dixon methods for fat suppression.[16,17]

MRI with advanced MARS exploits multispectral (MAVRIC) and multispatial (SEMAC) imaging methods to further decrease artifacts and are superior to conventional MRI in the visualization of the prosthesis-bone interface and periprosthetic tissues.[54,55] These can be combined with techniques such as a view angle tilting (VAT) compensation gradient (SEMAC-VAT)[56] or a hybrid form of MAVRIC and SEMAC called MAVRIC-Selective (MAVRIC-SL)[57] to achieve even better susceptibility artifact correction.

The use of MAVRIC in THA showed high specificity (99%) and positive predictive value (77%) for infection, although it was not sensitive in MoM bearings or the presence of ARMD.[58] MAVRIC-based T2 mapping has also been proposed as a quantitative assessment tool for periprosthetic synovitis.[59]

MAVRIC-SL data may be processed using magnetic field perturbation mapping to calculate metallic soft tissue deposition, which correlates with symptoms and tissue necrosis.[60] More novel techniques such as isotropic MAVRIC-SL have been reported to improve visualization of lesions, synovium, and periprosthetic bone with less blurring.[61] Robust principal component analysis MAVRIC-SL was shown to reduce scan time compared to conventional MAVRIC-SL, with almost equivalent diagnostic performance.[62]

Artificial intelligence

Artificial intelligence technology has potential applications in various aspects of arthroplasty surgery, from surgical risk prediction, patient outcome monitoring, and diagnostic image recognition. Shah *et al*. reported that machine learning could detect implant loosening on radiographs with accuracy, sensitivity, and specificity of 88.3%, 70.2%, and 95.6%, respectively, when combined with information on the patients' history.[63] Deep learning models can distinguish between implant manufacturer and type based on AP radiographs, achieving 99% accuracy for the knee[64] and 95%–100% for the hip,[65,66] similar to or exceeding expert human readers. This could play a key role in expediting preoperative planning of revision arthroplasty. Deep learning has also been shown to measure acetabular component angles on radiographs with high enough accuracy for clinical use.[67]

Conclusion

The wide spectrum of arthroplasty-related complications requires knowledge of patient and surgery-specific risk factors, and complementary imaging modalities to form an optimal diagnostic strategy. We propose an imaging algorithm [Figure 7], but each department should tailor this according to their MDT opinion and resource availability. Initial assessment with serial radiographs is critical to identify subtle changes in component position or periprosthetic lucency. CT or MRI with MARS techniques is particularly helpful in assessing long-term complications of osteolysis, infection, or ARMD. Nuclear medicine imaging is a problem-solving

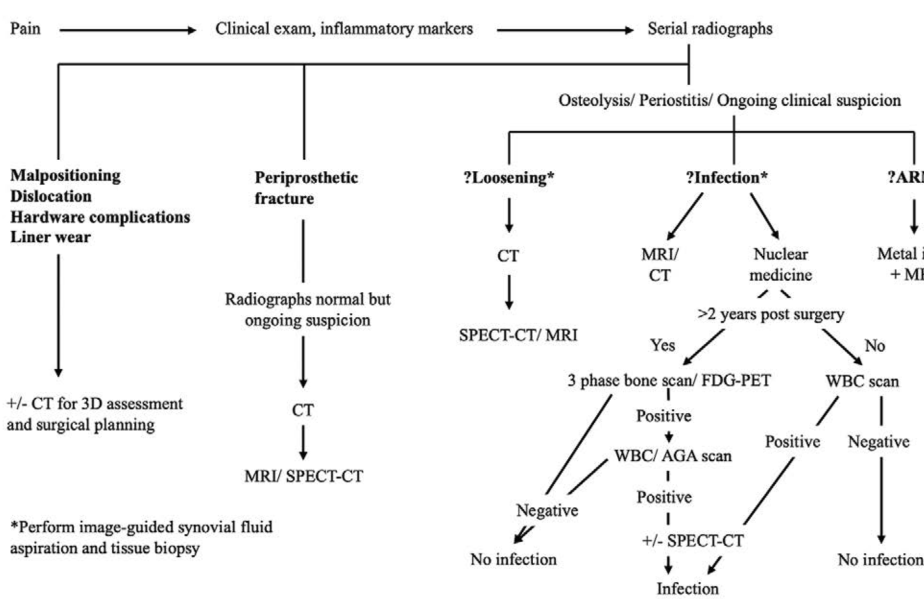

Figure 7: Imaging algorithm for the evaluation of the painful arthroplasty. Nuclear medicine imaging recommendations for infection were based on expert consensus opinion.[40] ARMD: Adverse reactions to metal debris, SPECT-CT: Single-photon emission computed tomography-computed tomography, FDG-PET: Fluorodeoxyglucose-positron emission tomography, WBC: White blood cell, AGA: Anti-granulocyte antibodies

tool and valuable in its high negative predictive value. Novel imaging techniques can further reduce artifacts and improve visualization, and machine learning can facilitate image interpretation although achieving sufficient data and clinical validation will be challenging.

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Conflicts of interest

There are no conflicts of interest.

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Intraoperative Radiological Imaging: An Update on Modalities in Trauma and Orthopedic Surgery

Mahtab Afzali[1,2], Parham Shojaie[1,2], Karthikeyan. P. Iyengar[3], Neha Nischal[1], Rajesh Botchu[1]

[1]Department of Musculoskeletal Radiology, Royal Orthopaedic Hospital, [2]Aston Medical School, Aston, Birmingham, [3]Department of Orthopaedics, Southport and Ormskirk Hospital NHS Trust, Southport, UK

Abstract

Intraoperative radiological imaging plays a key role in the management algorithm of patient care. Different intraoperative modalities have applications in the diagnosis, treatment, and monitoring of patient affected by various medical or surgical conditions. Advances in technology, computer software, and integration of various radiological modalities have extended the applications of intraoperative imaging in health care. Intraoperative radiological imaging have evolved from the initial use of conventional fluoroscopy to current innovations of computed tomography (CT) such as three-dimensional cone-beam CT and magnetic resonance-based imaging. In fact, intraoperative imaging has become integral to most of trauma and orthopedic procedures. Apart from their role in diagnosis of a spectrum of orthopedic conditions like prosthetic joint infection, imaging systems assist orthopedic surgeons to perform minimally invasive procedures, improving patient safety and also enabling higher accuracy and lower revision rates. More importantly, advances in technologies are essential in safeguarding radiation safety regulations, thereby reducing the radiation dose to the patient and surgical team. Integration of various imaging technologies, improving quality of image acquisition, reduction of radiation dose, and seamless image transfer to allow decision-making process are crucial in the delivery of effective patient care.

Keywords: C-arm, computed tomography, cone-beam computed tomography, fluoroscopy, magnetic resonance imaging, navigation, O-arm, surgery, three-dimensional intraoperative imaging, ultrasonography, ultrasound

Introduction

Intraoperative imaging is an essential technique that assists surgeons in obtaining information about the position of instruments relative to the patient's anatomy and monitoring interventional processes.[1] The emergence of mathematics, computer science, physics, medicine, and radiology has led to the introduction of imaging inside the operating rooms.[2]

More than ever, these imaging modalities are required in trauma and orthopedic surgeries. Imaging applications allow visualization of anatomy and increasingly permit minimally invasive procedures.[3] The primary evaluation tool in trauma and orthopedics is plain radiography (X-ray). After the development of "mobile X-ray" units by Madame Marie Curie, this evaluation tool has evolved to be utilized in trauma and orthopedic operating rooms. Real-time images produced by fluoroscopy units replaced the static images produced by radiography. These were then advanced to develop c-shaped "C-arm" machines that provide radiographic images from various angles with the ability to view, manipulate, store, and transfer the images using a computer workstation.[4] Further advances allowed the introduction of three-dimensional (3D) intraoperative imaging enabling better visualization of areas with complex anatomical structures such as the pelvis and acetabulum.[5]

Various intraoperative imaging modalities have been analyzed in the literature, such as comparison between intraoperative ultrasound (IOUS) and fluoroscopy and differences between O-arm and C-arm scanners.[6,7] Unfortunately, no prospective study has been done comparing two groups of patients

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Address for correspondence: Dr. Rajesh Botchu, Department of Musculoskeletal Radiology, Royal Orthopaedic Hospital, Bristol Road South, Birmingham, B21 3AP, UK. E-mail: drbrajesh@yahoo.com

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undergoing IOUS and fluoroscopy, and some of these data come from retrospective studies, which are prone to bias.[8] Cost–benefit analysis of intraoperative imaging scanners has challenged the use of advanced imaging modalities, as the most recent machines (e.g., 3D imaging systems) cost at least twice more than a standard fluoroscopy unit (C-arm flat-panel detector [FPD]).[2] Another challenging aspect of X-ray-based intraoperative imaging is related to radiation exposure. A suitable imaging modality should be chosen based on a risk–benefit assessment on a case-by-case basis. Furthermore, the recent literature has demonstrated various methods to improve education on radiation safety and minimize radiation exposure to the surgical staff.[2,9]

With the recent advancements in intraoperative imaging, focus is increasing on minimizing ionizing radiation by introducing tools like magnetic resonance imaging (MRI) to trauma and orthopedic theaters.[10]

This narrative review highlights the evolution of different modalities of intraoperative radiological imaging, their relative merits, and applications. Advances in techniques, computer technology, and future perspectives of intraoperative radiological imaging, specifically in the field of trauma and orthopedic surgery, is explored.

X-ray Fluoroscopy

There are many types of fluoroscopes that are used in surgical theaters worldwide, with the most common of them being the C-arm fluoroscope[11] [Figures 1-6]. One of the benefits of this mobile device is its ability to record images at various angles, as it can attain different positions. However, on the downside, it causes radiation exposure to surgical staff and patients. Hence, the fundamental radiological principles should always be followed, which includes justification between benefits and risks. However, based on a study in 2015, C-arm fluoroscopy, primarily used in orthopedic surgery, has demonstrated a short fluoroscopy time with a mean value of 78.53 s, a low mean dose area product of 0.27 ± 0.54 mGy-m^2, and an effective dose equivalent to 5.40 ± 10.80 mSv.[12] It is worth mentioning that in between orthopedic surgeries, posterior lumbar fusion was found to have the highest dose area product (1.20 ± 0.82 mGy-m^2) and effective dose (24.2 ± 16.40 mSv).[12]

The other main issue is the presence of artifacts in the scans when patients with previous metal inserts undergo intraoperative X-ray fluoroscopy.[13]

Intraoperative Ultrasonography

The capability of ultrasonography to capture images in real time enables it to be used as a method for navigation and direct localization during surgical procedures.[1]

Intraoperative ultrasonography (IOUS) produces high-resolution images.[14] This technique optimizes surgical operations in many different ways. IOUS enables accurate localization of the pathology, which in turn limits the extent of surgical incision.

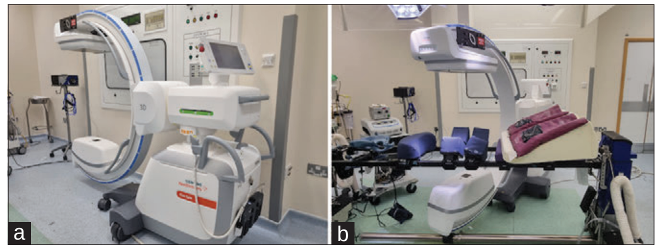

Figure 1: (a) Intraoperative “C-arm” fluoroscopy in orthopedic surgical practice. (b) Mini C-arm, primarily used in surgeries involving the extremities as opposed to standard C-arm which can be used in surgeries involving both axial skeleton and extremities

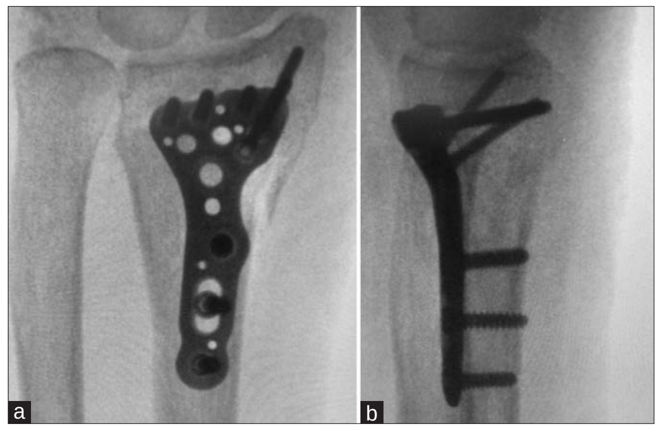

Figure 2: Anteroposterior (a) and lateral (b) Intraoperative “C-arm” fluoroscopy images following plate and screw fixation of fracture of distal radius

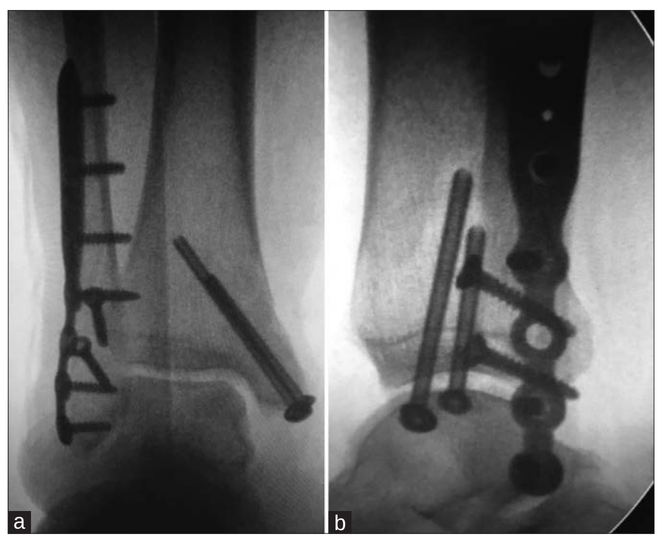

Figure 3: Anteroposterior (a) and lateral (b) Intraoperative “C-arm” fluoroscopy images of plate and screw fixation of bimalleolar fracture of the ankle

In addition, it guides biopsies during the surgery and surface incisions when deep resections are intended.[14]

It is worth comparing IOUS and fluoroscopy in joint aspiration procedures. According to a retrospective study

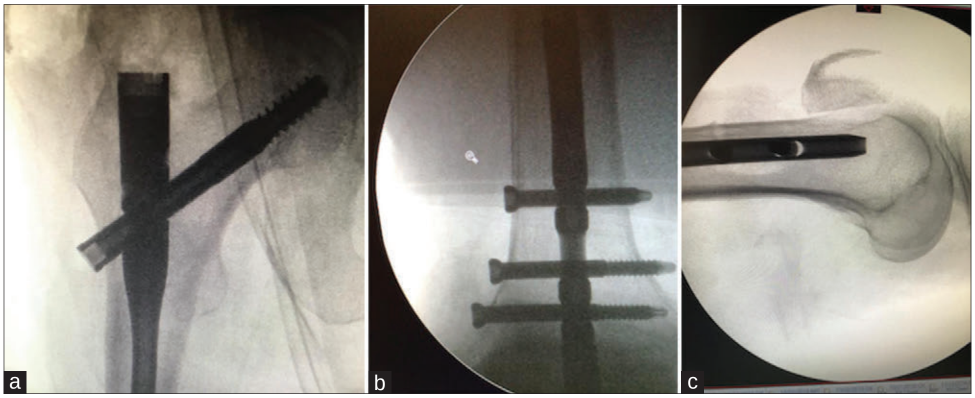

Figure 4: Anteroposterior (a and b) and lateral (c) Intraoperative "C-arm" fluoroscopy images of interlocking nail fixation of femur

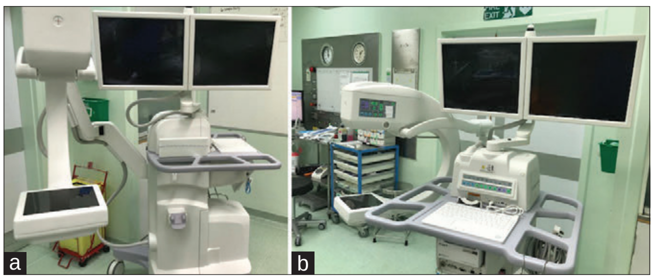

Figure 5: (a and b) Mini C-arm positioned in the operating theater

Figure 6: Fluoroscope (C-arm) positioned in the operating theater

done on 206 patients who were undergoing aspiration of the glenohumeral joint, there was no significant difference between fluoroscopy (70.6%) and ultrasound (69.4%) success rates when the patient's body mass index (BMI) was <35. Ultrasound (US) would be more suitable in these situations as it is less expensive, avoids radiation exposure, and causes less discomfort for patients.[8] However, fluoroscopy was favored in patients with higher BMI (>35), as more fluid was aspirated with this imaging technique compared to ultrasound.[8]

In surgeries that involve lower extremity joints, ultrasound also plays an important role. Some procedures are even performed better with ultrasound than with other radiology modalities. For instance, in aspiration of hip joint, ultrasound guidance was found to be more successful than fluoroscopic guidance, with an estimated 2.1 times greater fluid aspiration.[15] IOUS can be used instead of standard X-ray for patients with BMI <35, with added advantages of better accessibility and its ability to image the joint anterior to posterior[16] [Table 1].

Intraoperative Computed Tomography

Computed tomography (CT) and MRI are essential tools in diagnostic radiology and play a paramount role in providing preoperative image data. Several intraoperative imaging modalities are used to aid navigation during surgery, and these modalities are based on either CT or MRI.[18]

Cone-beam computed tomography

These systems are composed of a scintillation counter and fluoroscopy units.[2]

This technology was initially used in dental procedures, and after sometime, orthopedic surgery was adapted to utilize this technology.[2]

Cone-beam CT (CBCT) yields accurate 3D images of hard tissue structures.[19] It enables the production of true-size 3D images of the structures with less energy consumption and lower irradiation dose compared to conventional CT.[2]

A study conducted by Slomczykowski *et al.* concluded that since CBCT started to be used instead of postoperative multislice CT (MSCT), the cumulative dose was reduced for patients.[20]

On the downside, CBCT reduces information on neighboring soft tissues, and size of the device decreases the examination field.[21] Patients who undergo CBCT scans should not move or breathe as this impacts the quality of the scan. This issue introduced new challenges to procedures that are done under local anesthetics. The new version of this device (i.e., Surgivisio® system) uses a unique approach that allows scanning even when patients breathe.[21]

Table 1: The comparative utility of intraoperative X-ray fluoroscopy and ultrasonography intraoperative ultrasound in clinical practice

	Intraoperative X-ray fluoroscopy	IOUS
Availability	Universal	Lower[8]
Ionizing radiation	Yes	No
Safety profile	Ionizing radiation may be received by both patient and staff	None
Certification	IRMER 2017 academic certification required to operate	Competent and trained to use
Radiation dose monitoring	Required	None
Cost	Lower	Higher
Imaging view	Superficial and deep structures[45]	Restricted ability for deep structures[45] Impedance due to osseous structures and echogenicity
Operator skill	Dependent on radiographer skills to obtain optimal images	Operator-dependent
Common applications	Fracture fixations in OT	US-guided aspiration
Hip arthroscopy/ glenohumeral joint aspiration	Preferred modality in patients with BMI >35[8,16]	Preferred modality in patients with BMI <35[8,16]

US: Ultrasound, IOUS: Intraoperative ultrasound, IRMER: Ionizing radiation (medical exposure) regulations, OT: Operating theater, BMI: Body mass index

It is worth mentioning that another limitation of the CBCT is its unique conical shape which results in photon scatteration, and eventually, image degradation.[22]

Even though various propositions exist to increase image quality in CBCT, none have led to any adequate solution.[23]

There are even more advanced devices that use CBCT technique, and among them, the current market leader, O-arm® (Medtronic), uses a technology that combines CBCT FPD imaging with a navigation system.[2] FPDs are new-generation detectors that have replaced image intensifiers.[24] These FPDs have several benefits over a C-arm as they produce higher quality images with lower radiation dose.[25,26]

Multislice computed tomography

When a multidetector row system is incorporated with a CT scan, it is called MSCT. This technology can produce a high-quality 3D image in a short acquisition time which can be used to visualize the implants in spinal surgery.[27]

There are some limitations to using MSCT in operating theaters. Even though MSCT produces high-resolution images, it requires large equipment, has a significant radiation dose, and causes anesthetic constraints. Its use is limited to specific surgeries where the benefit–risk ratio is balanced and performed in high-risk areas (e.g., neurosurgery and spinal surgery).[2]

Intraoperative Magnetic Resonance Imaging

The primary use of MRI is to scan soft tissues in the body. It has a magnetic field and radio frequency waves (RF pulses) that cause H+ proton to spin, and when RF pulses have stopped, the energy released from H+ proton forms an image. Modifying this device's gradient and RF pulses allows for capturing images in a specific sequence, such as perfusion MRI (Pe-MRI), diffusion-weighted imaging (DWI), and MR venography or angiography.[28]

This wide range of modalities of MRI is one of its main advantages. It can produce a high-quality image and provide these scans in multiplanar 2D images or even in a 3D isotopic voxel. Furthermore, ionizing radiation is not used in this imaging technique.[23]

However, to use this scanner intraoperatively, some advances are required. As MRI is formed from magnets, patients with metal implants and devices cannot undergo this imaging technique. Moreover, most surgical instruments are ferromagnetic, and their use is restricted in operations incorporating MRI.

Another limitation is the design of the MRI. It has an immobile, fixed, and circular appearance which limits the access to the patient and requires an enlarged operating room to accommodate this device.[10]

Three-dimensional Intraoperative Imaging

Isocentric C-arm with three-dimensional imaging

Isocentric C-arm with 3D imaging (Iso-C3D) is a portable CT unit with a particular C-arm over a 190° orbital arc and acquires intraoperative imaging data. As opposed to the standard C-arm utilized in two-dimensional fluoroscopy, Iso-C3D spins around an isocentric point while maintaining a constant distance between the X-ray tube and the marked area. This technology has the broadest aperture among all the intraoperative CT devices. This feature enables Iso-C3D to obtain around 100 equidistant fluoroscopic images in 2D formats that are then reconstructed into a 3D image. In addition, this device allows the registration of patients' anatomy for navigation during operation. It is worth noting that this device can also function as a standard C-arm, and outside the surgical theater, their resolution is similar to CT for diagnostic assessments.[18]

O-arm Device

The O-arm imaging device has a fully rotational system that captures images over a 360-degree arc. It has two modes, the standard mode and the high-definition mode. The high-definition mode captures 750 images in 26 seconds, while the standard mode acquires 391 images in around 13 s.

One of the primary uses of this navigation technology in trauma and orthopedic surgery is during spinal surgery. This is because patients' anatomy can be registered to the O-arm device, which allows effective spinal navigation during procedures[18] [Table 2].

A report in 2011 underlined that the use of O-arm for pedicular screw placement results in lower rate of extrapedicular trajectory and surgical revisions. Moreover, it has demonstrated that the time at which the screws are inserted was reduced by 49%. Overall, it promises more efficient operations.[2]

O-arm devices are not only able to maintain the operation flow by rapidly capturing the imaging data after the scan but also in spinal surgeries, O-arm devices can expand their field of view to five levels of spine with 360° rotation.

According to a prospective study on spinal surgery that included 1922 thoracic, lumbar, and sacral pedicle screw placements under an O-arm device, the misplacement rate was 2.5%; nevertheless, these misplaced screws were fixed by the end of the procedure, so no revised surgery was required. This study suggests that using the O-arm, the navigation in surgeries can be improved, and less revision surgery rates are required.[18]

Isocentric C-arm with Three-dimensional Imaging Applications in Trauma and Orthopedic Surgery

Pelvis and acetabulum

Standard fluoroscopy is of limited use in visualizing the pelvis and acetabulum due to this joint's intricate anatomy. Therefore, surgeons operating in this region benefit significantly from intraoperative CT. In general, fluoroscopy aids with reduction and initial fixation, after which CT scan during surgery is used for precise assessment and correction of mal reductions. Moreover, this seizes the need for a postoperative CT scan and reduces the total radiation dose to the patient.[5]

The recent studies advocate using 3D intraoperative imaging as it lowers the rate of implant misplacement, fracture malreductions, complications, and revision operations and helps surgeons reach favorable outcomes when managing pelvic and acetabular fractures.[30] Furthermore, reports have demonstrated that ISO-C3D enables surgeons to better assess hip stability during stress tests for acetabular posterior wall fractures compared to conventional fluoroscopy.[31]

Table 2: Relative efficacy and accuracy of isocentric C-arm three-dimensional imaging and O-arm in intraoperative imaging applications

	C-arm (ISO-C3D)	O-arm
Angle (°)	190	360
Radiation to patient	Lower[17]	Higher[29]
Radiation to surgical staff	Higher[17]	Lower[29]
Accuracy	Lower[7]	Higher[9]
Efficiency	Higher[7]	Lower[9]

ISO-C3D: Isocentric C-arm with three-dimensional imaging

As previously mentioned, an additional application of intraoperative CT is in percutaneous iliosacral screw placement.[5] Literatures comparing 2D versus 3D fluoroscopy-based navigation found that the use of 3D fluoroscopic navigation reduces the screw perforation rate from 14%–20% to only 7%.[32,33]

Axial skeleton joints

Iso-C3D has a crucial function in spinal surgeries by providing real-time scans that are 3D. Similar to O-arm devices, iso-C3D can scan up to three to five spinal levels. When a 3D scan, wide field of scan, and device's navigation modalities are coupled, surgeons can easily track their instruments while performing complicated surgeries.[18]

Perforation is one of the main risks of pedicle screw placement that can be due to the lack of accuracy. Hence, Ishikawa *et al.* explained that ISO-C3D has high navigation accuracy, lowering perforation risks compared with other imaging techniques. Similarly, Tian *et al*. analyzed this matter in a cervical screw placement in a cadaver study and concluded that ISO-C3D has a higher accuracy than other modalities of imaging intraoperatively.[18]

Besides navigation, ISO-C3D can detect cortical violations in surgeries involving pedicle screws. According to Wang *et al.*, this factor of this device has improved the safety of spine surgeries.[18]

Overall, ISO-C3D has the main disadvantage, which is its limited ability to rotate, with its full rotation being 190 degrees. This limitation has led to interruptions in the flow of procedures and long surgical time. On the other hand, this device can provide a navigation platform, so surgeons can insert pedicle screws safely at all spine levels. Moreover, it is favored over conventional fluoroscopy as it demonstrates 3D scans, reduces the pedicle screw perforations, reduces the radiation exposure to both patient and surgical staff, and allows the performance of minimally invasive lumbar surgeries and spinal deformity surgeries.[18]

Fixation of intra-articular fractures

Iso-C3D is also valuable in intraoperative imaging for articular fracture fixation.

A study done by Atesok *et al.* evaluated ISO-C3D in the fixation of 72 intra-articular fractures. The result showed that 11% of these fractures (eight out of 72) required extended surgery after being scanned by ISO-C3D intraoperatively. The mean time added to the surgery due to the use of this device was 7.5 min.[29]

Ultimately, all procedures were satisfactory, and no case required revision surgery. Overall, this study concluded that these fractures may be missed by C-arm fluoroscopy, which can be avoided if ISO-C3D is used instead.[29]

Radiation Safety

Patient radiation exposure

Most of these intraoperative imaging modalities come with the risk of radiation to patients and surgical staff. It has been proven that radiation causes various detrimental effects on the human body. The two primary harmful sequelae of radiation are oncogenic effects and disruption in the function of organs.[2,34] These effects on organs are correlated with the concept of dose absorbed (D) in gray (Gy). For instance, 2.5-6 Gy results in female sterilization, 0.15 Gy causes male sterilization, 5 Gy leads to cataracts, and 0.5 Gy is enough to cause hematopoiesis suppression.[2] The oncogenic effect of radiation is due to the effective dose (E), which is presented in millisieverts (mSv). Nonetheless, the linear no-threshold model is used to assess cancer progression, and the epidemiological, epigenetic data have helped in the risk assessment in this matter.[2]

Radiation exposure should always be balanced with benefits such as reduced rate of revision surgery, operation time, and surgical complications. A great benefit of using radiation-based devices in surgery is how they allow operations to move toward minimally invasive procedures.[35] Hence, based on the procedure, surgical staff must use the most suitable imaging method to achieve all these benefits, which is more achievable due to the presence of new technologies.[17]

Surgical staff

Surgical staff can accomplish safety toward radiation using appropriate personal protective equipment, following available safety policies and educating themselves about techniques to reduce the risk of radiation exposure.[17,36]

However, various factors have resulted in operation room staff facing barriers to achieve the lowest risks from the radiation of these imaging modalities.

Despite the excessive usage of lead aprons, some body regions are not well protected from intraoperative radiation. An article in the Journal of Bone and Joint Surgery stated that the breast tissue's upper outer quadrant (UOQ), a high-risk area for cancer, is not well protected against radiation when female surgeons only wear their standard lead aprons and vest. Therefore, it has been suggested that orthopedic surgeons should wear axillary supplements and sleeves during surgeries, as they significantly reduce radiation exposure to UOQ of the breast.[37]

Overall, a need for a better educational program regarding radiation safety has been identified.[38] Various methods have been proposed to enhance training in this field. Süncksen *et al*. argue that scattered radiation of C-arm devices can be better comprehended through interactive visualization, which can be achieved using virtual reality simulation of scattered radiation.[9]

Recent Advances and Future Perspectives in the Field of Intraoperative Radiological Imaging

Intraoperative MRI

The recent advances in intraoperative imaging have led to the presence of two different designs of intraoperative imaging MRI.[39] One is a portable low-field scanner with a gap to access the patient during surgery and a static magnetic field of ≤ 1T.[40] The other available design is the high-field scanner. This design produces a higher image quality than a low-field scanner and can acquire different sequences such as DWI and Pe-MRI. It has a static magnetic field of ≥ 1.5T and a ceiling rail that allows the operative table to move into the scanner.[41]

All in all, intraoperative MRI is predicted to be more present in future, especially with the increased number of hybrid operating rooms.

Hybrid surgical rooms

Hybrid surgical rooms are specific theaters that have multimodal imaging systems.

Some hybrid surgical theaters can have high-field intraoperative MRI, position emission tomography, and CT scans in an identical room.[23]

These imaging modalities in one room benefit both the patients and surgical staff.

From the patient's point of view, these imaging techniques allow various surgeries to happen simultaneously, reducing the patient's hospitalization time. Plus, surgical procedures can be more easily changed when surgeries get complicated.

On the surgical staff end, hybrid rooms' imaging techniques allow more efficient visualization of real-time images.[23]

All these advancements in intraoperative imaging will reach the point that these suites will be flexible and accessible, so all the surgical theaters can be hybrid.[23]

Smart glasses

The use of smart glasses by surgeons in the operating room has gained more popularity over the past few years [Figure 7]. These glasses are especially useful in orthopedic theaters, where intraoperative imaging is particularly common. In theaters, these glasses are worn by the surgeons allowing them to visualize intraoperative imaging as a heads-up display throughout the operation.[42] In addition, these devices are used for educational purposes, vital sign monitoring, live stream transmission, surgical telementoring, communication, and audio-visual recording for documentation.[43] Reports have shown that these smart glasses improve ergonomics and accuracy in surgical settings. An example of these smart glasses is Moverio BT-35E (Suwa, Japan: Epson Inc.), which has been used in complicated orthopedic surgeries like hindfoot nailing of an open ankle fracture in a patient with multiple comorbidities.[42] Overall, more research is required to evaluate the benefits of these smart glasses' intraoperative imaging display function in orthopedic theater. These can be used in conjunction with robots for computer-navigated surgeries [Figures 8 and 9].

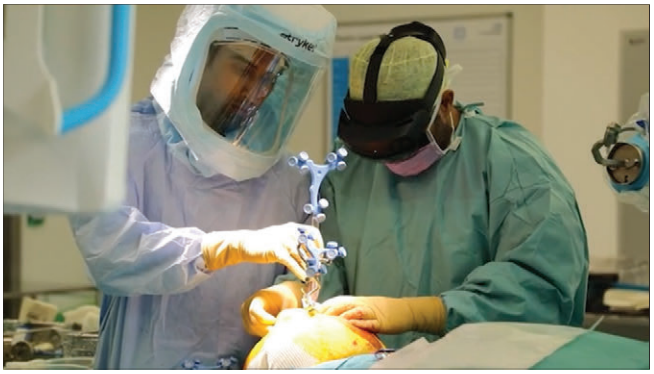

Figure 7: Surgeon using HoloLens while performing computer-navigated knee arthroplasty

Figure 8: Robot– ROSA used for RAS in total knee arthroplasty. RAS: Robotic-assisted surgery

Figure 9: Intraoperative imaging of RAS in total knee arthroplasty. RAS: Robotic assisted surgery

Cost Implications of Intraoperative Imaging Modalities

The surgical market can be separated into different segments: neurosurgeries, cardiovascular surgeries, gastrointestinal surgeries, orthopedic and trauma surgeries, and others. Among all, orthopedic and trauma surgeries have been growing the fastest, and one of the reasons is the high use of intraoperative imaging in these surgeries, like 3D navigation, to achieve minimally invasive procedures. There have been multiple factors that are causing growth in the market of intraoperative imaging itself. These can include increased use of FPD C-arms instead of image intensifiers, as well as cuts in reimbursements of analog radiological systems and technological advancement. These factors have caused the intraoperative imaging market to be predicted to reach a growth of 2.4 billion USD by 2025. Nonetheless, the cost of these new advancements can prevent this market growth.[44]

Conclusion

All in all, intraoperative imaging has been beneficial in maximizing patient safety and suitable surgical outcome. Fluoroscopy was one of the first imaging modalities that allowed surgical staff to perform minimally invasive techniques. On the other hand, IOUS allowed procedures such as joint aspiration and arthroscopy to be performed safely. The recent advancements have led to bring 3D imaging into the operating theaters (e.g., ISO-C3D), taking large appliances to the operating rooms (e.g., intraoperative MRI) and even designing surgical theaters that contain different imaging equipment (hybrid OR). However, radiation control is still one of the main factors that surgeons must always consider. They should try their best to protect themselves with various shields and patients by assessing the risks and the benefits.

In the end, even though it has been shown that intraoperative imaging is one of the main factors that has helped the orthopedic and trauma market, there should be more health economic studies to evaluate their cost benefit.

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Conflicts of interest

There are no conflicts of interest.

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Imaging in Sports Medicine

Hossein Abdolmohammadpour Bonab[1], Dmitry Treytyak[1], Neha Nischal[2,3], Karthikeyan P. Iyengar[4], Rajesh Botchu[2]

[1]Aston Medical School, Aston University, Aston, [2]Department of Musculoskeletal Radiology, Royal Orthopaedic Hospital, Birmingham, [4]Department of Orthopaedics, Southport and Ormskirk Hospital, Southport, UK, [3]Department of Radiology, Holy Family Hospital, New Delhi, India

Abstract

Muscular, soft tissue, and bony injuries are common among athletes. Different imaging modalities can be used to assess these patients depending on the type of injury and the expert opinion. Multiple imaging modalities are used to diagnose, investigate, and decide an appropriate medical or surgical treatment. Among the modalities that are used, magnetic resonance imaging and ultrasound (US) are commonly used to illustrate soft tissue injuries. Radiographs are cheap and are commonly used. The British Athletic Muscle Injury Classification is a grading system used for muscle injuries and can be used to predict the time it takes for a player to return fully. Tendons and ligaments are graded from 1 to 3, and the Fredericson grading system is used to classify bony injuries. Many of the common sports injuries are graded using these grading systems. Good communication and collaboration among sports physicians, surgeons, and radiologists are essential to adequate injury management in athletes. Appropriate choice of imaging modalities, classification systems, and a knowledge of common sports injuries can facilitate this.

Keywords: British Athletic Muscle Injury Classification, computed tomography, exercise-related signal anomaly, fluoroscopy, Fredericson grading system, fusion imaging, interventions, magnetic resonance imaging, nuclear medicine, radiographs, ultrasound

Introduction

Sports injuries occur when athletes are exposed to a sport they train and compete in. The main goal of sports medicine physicians is to enable an athlete to return to competition after an injury. The complexity comes from a need to balance an athlete's return to sport against the risk of a worsening or recurring injury. An accurate assessment and prognosis must be done, and imaging is a key tool. Accurate imaging techniques allow for a reliable diagnosis, detailed investigation, and appropriate medical or surgical treatment. Many imaging techniques are currently available for clinical use, with magnetic resonance imaging (MRI) and ultrasound (US) being the most frequently used in sports medicine. Using a combination of imaging modalities, sports physicians can visualize soft tissues such as cartilage, tendons, and muscles in great detail and plan their treatment. A multimodality approach is preferred in many cases. Muscle injuries are one of the most common types of sports injuries and can have a negative impact on the careers of athletes. Sport-related muscle injury is "a traumatic distraction or overuse injury of the muscle leading to a player being unable to fully participate in training or match play." They are considered a major concern due to the loss of time for training and competition. Muscle injury represents more than one-third of sport-related trauma, and its incidence increases with age.[1] The risk of occurrence of this lesion is mostly observed in sports requiring maximal contractions, such as football and track and field. In these sports, muscle injury mainly affects biarticular muscles, particularly those with a high percentage of fast-twitch fibers.[2] Moreover, such injuries pose a challenge to decision-making, in particular regarding return to sport. Musculoskeletal imaging techniques are essential to better understand the mechanism and pathophysiology of sports injuries. This information can optimize the management of such injuries and accelerate overall recovery.

Incidence and Prevalence of Sports Injury

According to injury data in British Olympic athletes, about 67% of training interruptions were due to an injury. At least one injury every season occurs in 43% of athletes, with every injury

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Address for correspondence: Dr. Rajesh Botchu, Department of Musculoskeletal Radiology, Royal Orthopaedic Hospital, Bristol Road South, Northfield, Birmingham, UK. E-mail: drbrajesh@yahoo.com

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Table 1: Demonstrating advantage, disadvantages and practice applications of various imaging modalities

Modality	Advantages	Disadvantages	Practical Applications	Other features
X-ray	Fast. Inexpensive. Interpretation Widely available. Good visualisation of bone pathology. Lower radiation.	Some radiation. Restricted degree of differentiation for soft tissues. 2D image only.	Use in major trauma. Identification of bone pathology and foreign bodies. Used in OR to guide operation.	Different views can be obtained. Contrast can be given to visualise other structures.
Ultrasound	Fast. Inexpensive. Real-time. Good visualisation of soft tissues. No Radiation risk (pregnancy safe).	User dependant. Can't visualise deep tissues and bone. Patient BMI can reduce accuracy.	Can be used on the field to quickly assess injury. Visualise soft tissues like muscles, tendons and organs. Identifies free fluid. Can guide injections.	Different probs available. Sonoelastography. Doppler effect. Can be used in fusion imaging.
Fluoroscopy	Real-time video. Good visualisation of bones.	Expensive. High dose radiation. Less availability.	Can be used in OR. Can be used to ensure optimum function restoration.	Contrast can be used to visualise structures. Arthrography. Real-time radiation monitors used to monitor exposure.
CT	Fast. 3D image. High resolution. Good visualisation of bone, soft tissues and calcified lesions. Potential for artefact reduction.	Slower than X ray and ultrasound. Highest radiation exposure compared to other modalities. Limited diagnostic value in metal-related artefacts. Can't use it to assess soft tissues adequately.	Use in preoperative planning. CT-guided injections.	Standing CT Spectral CT Can be used in fusion imaging.
MRI	Highly detailed visualisation of soft tissues. High spatial resolution. No radiation (pregnancy safe).	Expensive. Time consuming. Not widely accessible. Inability to use with metal artefacts.	Intraoperative MRI guidance. Soft tissue pathologies. Nerve injuries.	Multiplanar MRI. Upright MRI. Can be used in fusion imaging.
Nuclear Medicine	Shows metabolic activity of tissues.	Use of radioactive materials. Expensive.	Detection of metabolic activity. Early detection of bone stress trauma.	Skeletal scintigraphy.

causing an average 17-day break from training and one missed competition. The incidence of injury during training is lower than when participating in competitions. Shoulder, lumbar spine, and knee injuries have been shown to significantly burden the total number of training days lost.[3] Quantifying injury occurrence by looking at who, where, and when athletes are affected can help to create strategies to control and prevent them. To assess sports injuries, multiple imaging modalities are available. The choice of modality and management depends on the type of injury. Another factor that can influence the choice of imaging modality and intervention is the location of the injury. The ankle, knee, and shoulder were the most common joints affected among footballers.[4]

Understanding the common types of possible injuries in sports can help choose the most appropriate imaging modality to investigate and treat the injury. Overall, muscle-related injuries are the most common type of injury in athletes. These muscular injuries account for more than 30% of injuries among footballers and over 40% among rugby players. Fractures were less common overall, accounting for only about 10% of the injuries.[5,6]

As multiple modalities are available, clinicians sometimes skip the classical first-line investigations like radiographs if they believe another modality is likely to provide more helpful information. This decision can be based on the clinician's experience and the most likely injury.

Imaging Modalities

Each imaging modality allows the operators and physicians to assess different injuries in different settings and scenarios. Ultimately, the clinician in charge of the patient's care can decide which modality is indicated. The advantages and limitations of each modality can affect this decision and the clinical applications of each imaging modality [Table 1].

Radiographs

Radiographs are commonly used as a first-line investigation. They are relatively inexpensive and have comparatively low radiation exposure doses. These are also more widely available and easier to interpret. Apart from fractures, they can be used to diagnose dislocations. Anterior shoulder dislocation is a common injury in sports trauma, radiographs

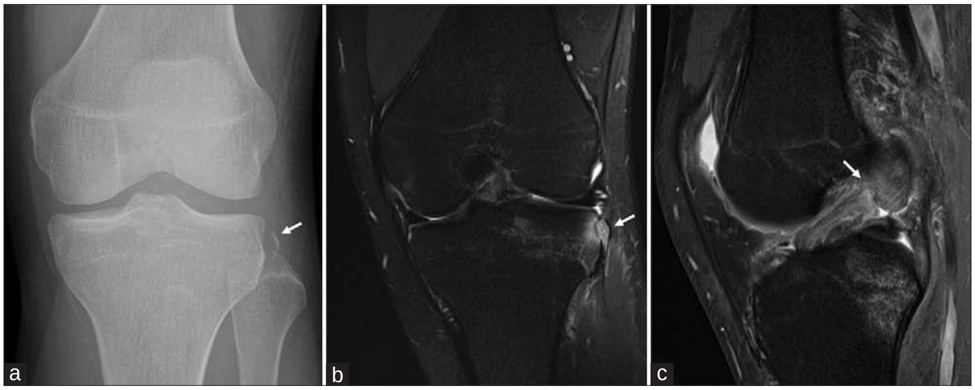

Figure 1: AP radiograph (a) of knee showing fracture of the lateral part of the lateral tibial condyle (arrow) – Segond fracture. PDFS coronal (b) and sagittal (c) showing Segond fracture (arrow) with full-thickness tear of ACL (arrow). PDFS: Proton density fat saturated, ACL: Anterior cruciate ligament, AP: Anteroposterior

Figure 2: Lateral knee radiograph (a) and sagittal CT (b) showing avulsion fracture of the tibial tuberosity (arrow). CT: Computed tomography

can help establish a quick diagnosis, but MRI or computed tomography (CT) might be needed later to assess glenoid loss, labrum, tendons, and ligaments.[7]

The evaluation of soft tissue injuries on radiographs is limited and inferior to US and MRI. Pathologies identified on radiographs include fractures, dislocations, erosions, calcification of muscle and ligaments, and foreign bodies [Figures 1 and 2]. There is a growing tendency for clinicians to proceed with an MRI or a CT without a radiograph when investigating a sports-associated injury.[7]

Ultrasound

US is one of the best modalities to visualize soft tissues and assess injuries in sports medicine. US allows for quick assessment of soft tissue injuries. Furthermore, it is relatively cheap and easily accessible. Overall, US can enable the user to assess the extent of the injury on the field (portable and mobile US), which can aid in decision-making and plan management. For instance, US can reveal the extent of intramuscular hematomas, tendon tears, ligament injury, and other soft tissue pathologies. It can also be used to monitor the healing process. The operator can visualize the injured muscles, ligaments and tendons for healing, fibrotic changes, and tissue remodeling. Another distinct advantage of using US is the ability to carry out a dynamic assessment. It can also guide interventions such as steroid injections.[8,9]

Tendons and muscles are relatively superficial, which makes them accessible for this imaging modality. High-frequency linear probes (>10 MHz) are usually used; low-frequency probes are preferred in certain patients with pronounced adipose tissue layers or high muscle mass. With the advancements in US imaging technology and software, there is an ability to obtain a spatial resolution measuring <200 μ with 0.5–1 mm thick tissue sections under optimal conditions that can even exceed the resolution of MR.[10] Sonoelastography can be a very effective tool in evaluating tendon pathologies. Unlike the conventional US, sonoelastography provides information on the tendons' mechanical properties.[11]

Doppler US combined with grayscale US is an appropriate tool for evaluating muscles, ligaments, and tendons.[12] In theory, minor muscle ruptures should elicit a Doppler response due to inflammation. However, distinguishing inflammatory flow from the preexisting resting muscle flow is a significant challenge. A grayscale US is usually the first line in sports-associated ligament injuries. The addition of color Doppler US will aid the evaluation of hypervascularization in conditions such as synovitis and tenosynovitis.[13] Recent advances in Doppler US in sports medicine were mainly focused on tendon pathologies. Color Doppler activity recorded in the tendons showed close correspondence to pain.[14]

The disadvantages of US are relative difficulty in visualizing deeper tissues and in patients with increased body mass index. US being user dependent with a steep learning curve means that utilizing the advantages of this modality will highly depend on the operator's expertise and experience in the field.

Fluoroscopy

Fluoroscopy is an imaging technique which uses X-rays to visualize the region of clinical concern. Therefore, most of the advantages and disadvantages of using radiographs apply to fluoroscopy with a few exceptions. The advantage of using the technique is that it generates a real-time view of the structures and can thus aid in procedures. For instance, fluoroscopy can be particularly useful during procedures such as arthrography, nerve root injections, and joint injections. The main disadvantage is the ionizing radiation dose generated by the device. However, radiation risk can be reduced by using new software, radiation protective equipment (lead aprons, thyroid protective shields, and radiation safety glasses), and real-time radiation monitors.[15]

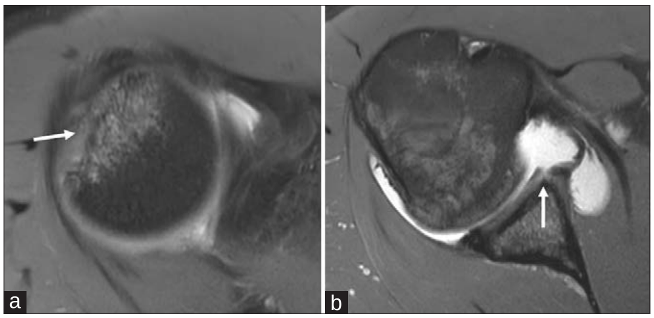

Figure 3: PDFS axial showing Hill–Sachs lesion (a) and anteroinferior labral tear (b) (arrow). PDFS: Proton density fat saturated

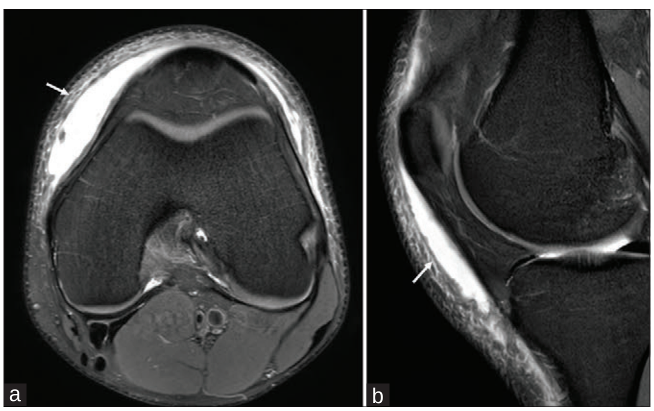

Figure 4: Arrow shows fracture PDFS axial. (a) and sagittal (b) showing large subcutaneous hematoma – Morel-Lavallee lesion. PDFS: Proton density fat saturated

Figure 5: Arrow shows fracture PDFS axial. PDFS sagittal showing full-thickness tear of ACL (a) and anteriorly flipped lateral meniscal tear (b). ACL: Anterior cruciate ligament, PDFS: Proton density fat saturated

Computed tomography-standard, standing computed tomography, and spectral (dual-energy) computed tomography

CT is a cross-sectional imaging technique with soft tissue contrast, which is considerably inferior to that of MRI. The most common applications of CT imaging in sports medicine are for suspected bone injury and in cases where MRI is contraindicated. CT is better than MRI at visualizing fracture lines and calcifications. Recent developments in metal artifact reduction software have improved the diagnostic use in patients with metal work. Another important role of CT imaging is to aid in percutaneous imaged guided procedures. The radiation dose has been reduced in newer CT scanners. Dual-energy CT is a new technique that has been developed. It uses two different energy spectra, so structures with different attenuation properties can be integrated to produce an image. In sports medicine, this can allow physicians to assess bone marrow edema.[16] This can potentially obviate the need for an MRI in some cases. Upright CT is another variation of this modality that allows for better tissue assessment under gravity. Assessing functional abnormalities and tissue alignments under gravity can aid the diagnostic process.

Magnetic resonance imaging-standard and upright magnetic resonance imaging

MRI is undoubtedly one of the top imaging modalities of choice in sports medicine, with numerous advantages. MRI provides high-contrast resolution images of soft tissues, joints, and bones. It is considered a reference modality for assessing muscle anatomy and pathology [Figures 3-6]. Using special sequences like T1 VIBE in patients with suspected pars fracture might negate the use of CT. This fracture is common in gymnasts and athletes who repeatedly bend their spine backward[17] [Figure 7].

MRI can be used to detect early changes in cartilage and joints [Figure 4]. An example of this is the use of T2-weighted mapping. T2-weighted mapping is a sensitive method to identify early degenerative changes in the water and collagen content of the joint cartilage. Techniques like T2 inversion can make evaluation easier for inexperienced readers, reducing the user experience dependency of the modality.[18] Some disadvantages of MRI are that it is relatively costly and requires longer scan times compared to other modalities. It is also not commonly used for image-guided procedures and interventions.

A classical supine MRI may sometimes fail to demonstrate structural problems in symptomatic patients. An example is the failure to show abnormalities in patients with lumbar back pain and radiculopathies. Upright MRI is a relatively new technique used to identify spinal abnormalities. Upright MRI can be used to decipher foraminal stenosis or disc pathologies. Imaging patients in their weight-bearing position and positions where the pain is demonstrated can also help clinicians identify pathologies that would not be visible in the conventional supine method.

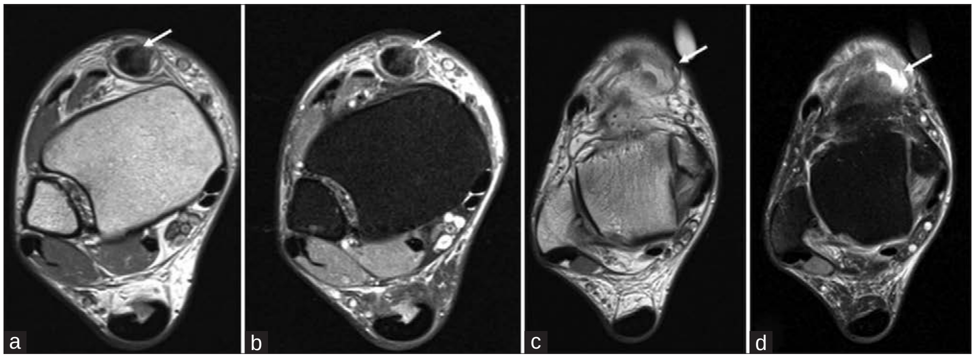

Figure 6: Axial PD (a and c) and PDFS (b and d) showing full-thickness tear of tibialis anterior (arrow). PDFS: Proton density fat saturated, PD: Proton density

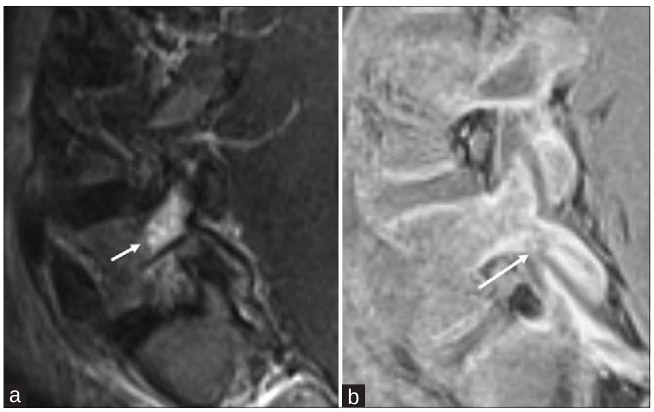

Figure 7: STIR (a) and T1VIBE (b) sagittal showing osseous edema of pedicle of L5 (short arrow) with incomplete fracture of pars (long arrow)

Previous research has suggested several imaging findings associated with the time elapsed before returning to play. Injuries involving the tendon are related to prolonged return to sport, particularly if it is a central or proximal tendon (free tendon) or near the tendon origin, and especially if there is retraction or loss of tension.[19]

Magnetic resonance neurography (MRN) is a relatively new imaging technique for diagnosing peripheral nerve injuries and disorders.

Recent developments in MRI hardware and software, such as the use of multichannel receiver coils and accelerated imaging techniques, have significantly impacted the advancement of MRN. It is commonly used in abnormalities anatomically located in the brachial and lumbosacral plexus, sciatic nerves, and the thoracic outlet. The main advantage of MRN over ultrasound imaging of nerve injury is better contrast resolution.[20] Dynamic contrast-enhanced (DCE) MRI is a technique that calculates perfusion rates by calculating T1 shortening induced by a contrast bolus based on gadolinium passed through the tissues. The K-trans calculation measures the accumulation of contrast agents in the extracellular spaces. DCE-MRI has the potential to demonstrate vascularity changes in tendons preoperatively and postoperatively when surgically managing tendon pathologies and for follow-up.

Nuclear medicine – Bone scan, single-photon emission computed tomography–computed tomography, positron emission tomography–computed tomography, and positron emission tomography–magnetic resonance imaging

Nuclear medicine imaging techniques can diagnose and monitor bone and soft tissue sports injuries. Skeletal scintigraphy is mainly used for the evaluation of bone diseases. It involves the use of injected radioactive materials that give off radiation which is then detected by a gamma camera visualizing bone architecture. This technology allows us to identify molecular activity within the bones and hence can aid in detecting subtle fractures though this is not routinely used. Bone stress injuries account for approximately 10% of sports injuries, with lower limbs mostly affected, followed by the spine. High-contrast resolution of this type of scan enables early detection of bone stress trauma and becomes positive within 6–72 h after the onset of symptoms. Skeletal scintigraphy may demonstrate uptake in fractures as well as in pathologies such as osteonecrosis, metastasis, and degenerative change.[21]

Fusion imaging - Single-photon emission computerized tomography, positron emission tomography–computed tomography, and positron emission tomography–magnetic resonance imaging

As the name suggests, fusion imaging utilizes a combination of two different imaging modalities to visualize a structure. One of the common fusion techniques in sports medicine is the MRI-US fusion technique. The advantage of this technique is the greater precision of this modality in detecting injuries while benefiting from the real-time image provided by ultrasound machines. This technique does not involve radiation. Overall, the research on this field is limited and more data in the field of sports injury are required. Thus, the exact effectiveness and outcome quality of this imaging modality remains unclear compared to other modalities.[22]

Interventions

The imaging modalities discussed earlier in this article can also be used to treat and correct some of the injuries identified by those modalities. US, for example, can be used to help the clinician perform guided injections. Three popular injections given under imaging guidance are steroids, platelet-rich plasma, and stem cell injections.

Steroid injections are widely used in medicine as a medical management for pain control. In sports medicine, these injections can be given on-site using ultrasound guidance to help the athlete complete the game or provide pain relief.[15]

Another example of an intervention using US imaging is the injection of platelet-rich plasma which is based on the remarkable ability of platelets to produce growth factors, promoting the regeneration of injured tissues.[23]

Prolotherapy is a procedure that involves injecting an irritant solution into a damaged ligament or tendon, activating an inflammatory response that is followed by the proliferation of fibroblasts and collagen synthesis. This promotes regeneration and recovery of tensile strength.

Injection of stem cells into joints promoting cartilage regeneration, into tendons in case of tendinitis, and into muscle tears to accelerate recovery is becoming more popular when treating sports-related injuries in professional athletes. However, there is limited scientific literature with definitive evidence.[24]

Classifications and Common Injury Examples

Muscle injuries and classifications

Muscle injuries are one of the most typical injuries in sports medicine. Most injuries occur due to the muscle belly being exposed to direct trauma or excessive stretching force. The most commonly affected muscles include the hamstring, quadriceps, and gastrocnemius muscles. The hamstring muscle injuries correspond to up to 16% of injuries in football, rugby, and athletics.[25] The preferred method of imaging is usually an US or MRI.

Figure 8: STIR coronal (a), axial PD (b), and PDFS (c) showing marked edema of the muscle of anterior compartment (arrow) in keeping with compartment syndrome. PDFS: Proton density fat saturated

A grading system would facilitate a more effective form of communication that can guide treatment and estimate the recovery time.[26] A combination of clinical features and MRI scans are used for most of these classifications. MRI-based classifications can also predict the time it takes for athletes to return to play. There are many classifications available, and there is a lack of consensus over which grading system is the most relevant and useful. Furthermore, the use of these classifications to estimate the time of returning to play is evidently limited. In 2012, a group of international experts in the field of sports medicine got together to design a classification system which is practical and scientific. This led to the creation of the Munich Consensus. Another more commonly used classification system is the British Athletic Muscle Injury Classification (BAMIC). This classification breaks down injuries into four grades (from 0 to 3), and an "a," "b," or "c" suffix is added if the injuries are identified as "myofascial," "musculotendinous," or "intratendinous." The BAMIC classification can also be used to estimate how long it takes for players to return to full-time training.[27] This classification can guide management and assess the risk of reinjury in hamstring injuries.

Exercise-related signal anomaly

ERSA lesions can be described as a slight increase in signal intensity when looking at fluid-sensitive imaging. These lesions also appear less pronounced than indirect muscle injury and do not have an edema pattern seen in acute muscle strains. Moreover, muscle fibers retain their architecture and show no focal disruption, unlike muscle tears. Tendons are not involved in ERSA lesions. Peritendinous ovoid region is defined as Type A, the subfascial ring is Type B, and Type C includes both types together.[28]

Delayed-onset muscle soreness

Another differential diagnosis of skeletal muscle edema on imaging is delayed-onset muscle soreness (DOMS), also known as "muscle fever." The etiology is believed to be temporary microstructural muscle damage after an intense, unfamiliar physical exercise, especially eccentric exercise that

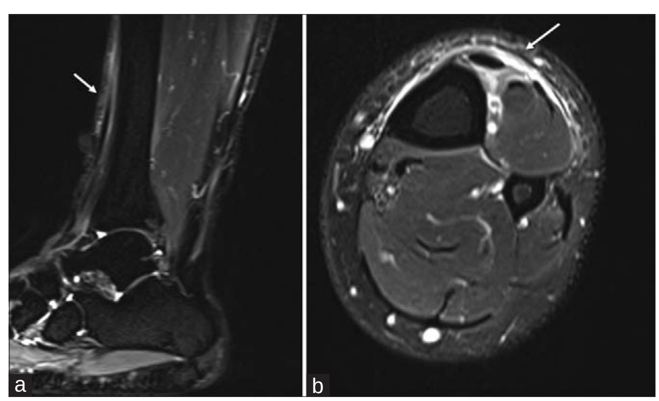

Figure 9: STIR sagittal (a) and axial (b) showing marked edema in relation to tibialis anterior (arrow) at the site of proximal part of the superior extensor retinaculum in keeping with tibialis anterior friction syndrome

results in greater muscle tissue disruption than concentric type. It has a 12–24-h period free of pain with soreness peaking at 24–72 h. On ultrasound, it presents as diffuse and well-defined hyperechoic regions in the muscle that also appears to increase in size with minimal hyperemia. On MRI imaging such as T2-STIR sequence, affected muscles have high signal, which may be present for months after symptoms have gone.[29]

Compartment syndromes

Compartment syndrome is commonly defined as an increase in pressure within a compartment which can compromise vascular integrity and ultimately damage the muscles and nerves. Acute compartment syndrome is considered a medical emergency and is normally diagnosed clinically with respect to compartment pressure. On MRI and US, some edema and ischemic changes may be present [Figure 8]. Imaging may delay treatment and hence is not routinely used. Diagnosing chronic exertional compartment syndrome (CECS) is commonly based on compartment pressure changes, but there is not enough evidence to suggest a definite diagnostic criterion.[30,31] MRI can be used in CECS cases to establish a diagnosis where compartment pressure measurement is unavailable or contraindicated.

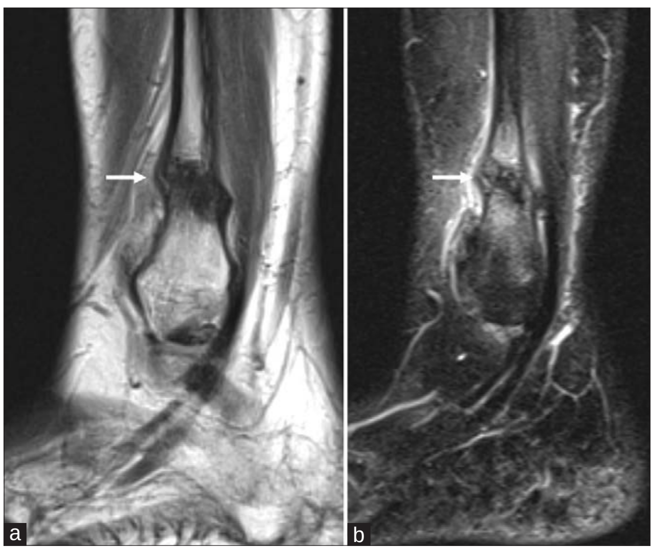

Figure 10: Arrow shows the stress fracture of distal fibula. PD (a) and PDFS (b) sagittal showing stress fracture of distal fibula with marked osseous edema (arrow) (Fredericson stress injury grade 4b). PDFS: Proton density fat saturated, PD: Proton density

Table 2: Fredericson classification of stress injuries

Grading	Periosteal oedema	Bone marrow abnormalities	Sequences revealing bone abnormalities
Grade 1	Present	Non	Non
Grade 2	Present	Mild oedema	Fat-suppressed T2WI
Grade 3	Present	Extensive oedema	Fat-suppressed T2WI and T1
Grade 4a	Present	Extensive oedema	Fat-suppressed T2WI and T1 few intracortical signal change foci
Grade 4b	Present	Extensive oedema	Fat-suppressed T2WI and T1+ linear intracortical signal change

Tendon and ligament imaging

While bone abnormalities can be seen on radiographs and CT, MRI and US are the common modalities for assessing tendon and ligament integrity. On ultrasound, a linear high-frequency transducer perpendicularly aligned to collagen fibers is required to visualize tendons. On MRI, stronger magnetic fields are preferred and hence 3T MRI is more desirable than 1.5T MRI. T2-weighted sequences can reveal fluids and tears on tendons, ligaments, and surrounding tissues [Figures 4-6]. Both techniques can thus provide valuable information, and the preference depends on the clinical scenario and expert opinion. These injuries are graded from 1 to 3, with 1 being just superficial high signal area and 3 showing a complete disruption on MRI.

Tibialis anterior friction syndrome is an example of exercise- and overuse-related injury, and it is seen in athletes who overuse their lower extremities. This is believed to be because of repeated friction between the superior extensor retinaculum and the tibialis anterior tendon. On MRI, edema can be present in the subcutaneous, myotendinous junctions and periosteal tissues[32,33] [Figure 9].

Bone injuries and their classification

Similar to muscle injuries, a comprehensive description is desired to describe bone injuries. There are multiple classifications available for bone injuries. Fredericson grading system is an MRI-based grading system which was initially developed to assess medial tibial stress lesions. Nevertheless, it can also be applied to grade other bones[34] [Table 2 and Figure 10].

Bone stress injuries account for 10% of all sports-related injuries. A bone stress fracture is an overuse type of injury. The highest incidence of stress fractures occurs in the group of track-and-field athletes.[35] Radiography and MRI are commonly used to diagnose stress fractures, and occasionally, a CT is used to investigate. Some stress fractures only appear on radiographs after several weeks of pain from the injury.

Conclusion

The role of radiological investigation is fundamental when diagnosing and managing sports injuries. Imaging also plays an increasingly important role in developing effective and comprehensive follow-up after sports injuries. There have been many advances that have had a tremendous positive impact on the state of imaging technology in sports medicine. Good communication and collaboration of sports physicians, surgeons, and radiologists is key to adequate management of injury in athletes. In this article, we provided an overview of existing and upcoming new imaging modalities, classification systems, technological improvements in radiology, and common injuries that are relevant for sports medicine professionals. Recently developed image-guided interventions were also discussed, focusing on their application in sports medicine.

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Conflicts of interest

There are no conflicts of interest.

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Knee Pain in Elite Dancers: A Review of Imaging Findings

Matthew Mariathas, Emily Hughes[1], Roger Wolman[2], Neeraj Purohit[3]

Department of Musculoskeletal Radiology, Nuffield Orthopaedic Centre, Oxford University Hospitals NHS Foundation Trust, Oxford, [2]Department of Sports and Exercise Medicine, Platinum Medical Centre, London, [3]Department of Musculoskeletal Radiology, University Hospital Southampton NHS Foundation Trust, Southampton, UK, [1]Department of Paediatric Radiology, British Columbia Children's Hospital, Vancouver, Canada

Abstract

Introduction: Musculoskeletal injuries are a frequent occurrence in dancers of all skill levels, and the knee is the most common anatomical location. Our purpose was to identify the specific knee injuries encountered in a large cohort of dancers presenting to a tertiary-level dance injury clinic with knee pain. The relevant imaging findings of the identified knee injuries are highlighted. **Methods:** All new patients referred to the specialist dance injury clinic between March 2012 and February 2017 were entered into a database. Those with a knee-specific injury were selected with documentation of relevant demographic information. Clinic notes were analyzed for information related to a preceding acute traumatic event, and any relevant imaging was reviewed. This formed the basis for the review with Pubmed being utilized to identify relevant papers on the specific pathologies including etiology, imaging findings, and management. **Results:** Data from a cohort of 197 dancers presenting with a knee complaint were reviewed, composed of 144 women and 53 men with an average age of 28 years (range: 12–75 years). The most common knee complaint was anterior knee pain ($n = 111$) followed by medial-side knee pain ($n = 42$). The most frequent diagnoses included patellofemoral pain syndrome ($n = 69$), medial meniscal injury ($n = 29$), and Hoffa's fat pad impingement ($n = 13$). **Conclusion:** An anatomy--based approach with regard to the site of pain can be useful in identifying any potential abnormality. Knowledge of the radiological appearances of the most frequently seen knee abnormalities in dancers will aid in prompt and correct diagnosis.

Keywords: Computed tomography, dancers, knee pain, magnetic resonance imaging, musculoskeletal radiology, orthopedics, sports medicine, trauma, ultrasound, X-ray

Introduction

Musculoskeletal injuries in dancers have been well documented and can occur in all dance forms and dancers of different skill levels.[1-3] The prevalence of injury has been reported to range between 20% and 84% with chronic overuse injury representing the most typical mode[4] and acute trauma seen less commonly. The knee is the most common anatomical site for injury, accounting for over 40% of injuries in some case series.[5,6]

There are numerous causative factors for dance-related injury including the type of dance, training schedule, improper technique, and anatomic structure.[7] Joint range of motion (ROM) and scoliosis have been identified as surrogates for potential future injury in young female dancers.[5] Another anatomical consideration related to the knee is the presence of patella-trochlear dysplasia. This morphological abnormality can lead to anterior knee pain and patella instability.[8] Ballet can be particularly demanding and involves long hours of rehearsal leading to altered biomechanics and potential injury. The female athlete triad (relative energy deficiency in sport) is also a factor to consider, comprising of anorexia, amenorrhea, and osteoporosis.[9] This condition may predispose to stress fractures and delayed healing.

Clinical assessment of dance-related injury involves a detailed history, and physical examination with relevant functional and provocative tests. Radiographs can be used as an initial first-line investigation but may not be clinically indicated in a dancer with a chronic overuse soft-tissue problem. Ultrasound (US) and magnetic resonance imaging (MRI) are

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Address for correspondence: Dr. Matthew Mariathas, Department of Musculoskeletal Radiology, Nuffield Orthopaedic Centre, Oxford University Hospitals, Windmill Road, Oxford OX37LD, UK.
E-mail: matthew.mariathas@gmail.com

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nonionizing forms of imaging and are preferred in detecting soft tissue pathology. Management in the majority of these cases is nonsurgical. Modification of training intensity and technique, physiotherapy, and analgesia often represent the mainstay of treatment.

This paper will review the demographics and imaging for a variety of knee-related complaints encountered in dancers presenting to a tertiary-level dance injury clinic. We believe this review will represent the largest cohort of dance-related knee injuries published.

Methods

All new patients referred to our specialist dance injury clinic between March 1, 2012, and February 28, 2017 were entered into a database. From this database, those with a knee-specific injury were selected. Demographic data, dance type, dance level, presence of trauma, and the final diagnosis were all recorded.

Clinic notes were retrospectively reviewed for details relating to an acute traumatic injury. All relevant radiological imaging was reviewed by the lead author. In cases where radiological investigations were not performed, the diagnosis was based solely on clinical assessment at the specialist dance injury clinic.

Cases were excluded when the injury was due to nondance-related causes (e.g. accidents at home).

Results

Data from a cohort of 197 dancers presenting with a knee complaint were reviewed. This comprised 144 females and 53 males with an average age of 28 years (range 12–75 years). A history of trauma was reported in 43 patients with the remaining 154 reporting no acute traumatic event.

The majority of the dancers were students (*n* = 85) followed by professionals (*n* = 72). Retired and ex-dancers represented the smallest group (*n* = 6). The most common knee complaint was anterior knee pain (*n* = 111) followed by medial-sided knee pain (*n* = 42), Table 1.

The dancing style most frequently represented by this cohort was contemporary (*n* = 69) followed by classical (*n* = 38), musical theatre (*n* = 23), and hip-hop/street dance (*n* = 18).

Table 1: Knee pain diagnoses in a cohort of Elite Dancers

Location/Pathology	Number
Anterior knee pain	
Hoffa's fat pad impingement	13
Osgood–Schlatter's disease	4
Patella tendon	10
Patella instability	12
Patellofemoral joint pain	69
Chondral injury	3
Total	111
Cruciate injury	9
Lateral knee pain	
Lateral meniscus	8
ITB	2
Other	5
Total	15
Medial knee pain	
Medial meniscal	29
MCL	5
Pes anserinus	3
Other	5
Total	42
Osteoarthritis	15
Other	5
Total	197

MCL: Medial collateral ligament, ITB: Iliotibial band syndrome

Figure 1: A 19-year-old female Jazz dance student with 6 months of anterior knee pain. Normal MRI Axial PDFS image (a) and sagittal PDFS image (b) PFP thought to be secondary to poor muscle conditioning and underlying hypermobility. MRI: Magnetic resonance imaging, PFP: Patellofemoral pain, PDFS: Proton density fat-saturated

Anterior Knee Pain

Patellofemoral pain

Patellofemoral pain (PFP) is a broad term used to describe anterior knee pain often around the patella.[10] PFP is commonly encountered in athletes and dancers and affects individuals with or without structural damage to the patellofemoral joint (PFJ).

When there is no structural abnormality to be seen on imaging, this entity is often referred to as PFP syndrome (PFPS) [Figure 1].[11] The pain generator is thought to relate to the patella and surrounding soft tissue structures including the retinacula, extensor muscles, and anterior knee fat pads.[10] The two major biomechanical factors involved in PFPS are patella maltracking and patella functional malalignment.[12] In patella maltracking during dynamic flexion and extension of the knee, there is a lateral translation of the patella.[10] Patella maltracking may be the result of imbalances in the activation and strength of the individual quadriceps muscles.[12] Functional malalignment (dynamic valgus) can be in the form of internal rotation of the femur as a result of weak hip abductors or internal rotation of the tibia with causes including pes pronatus or rear-foot eversion.[12,13] The most frequent presentation of PFPS is the anterior knee, particularly during activities that involve weight bearing of a flexed knee; these can include running, jumping, and squatting. The assessment for pain while squatting is a useful test during a clinical examination. Imaging can be used if there is suspicion that an underlying structural abnormality or static malalignment could be the cause of the knee pain or to assess.[14] Radiological confirmation of dynamic patella maltracking can be performed with dynamic MRI. Patellofemoral kinematics are assessed with the patient extending and flexing the knee during the acquisition of gradient echo or steady-state sequences.[10] The management of PFPS is focused on nonsurgical options with pain relief and attempted correction of underlying patella maltracking and functional malalignment. Physiotherapy can be utilized to build up the muscles that may be deficient causing the underlying issues including the hip abductors and quadriceps. Patella taping and application of a patella brace are two methods used to create a directed force to counteract the lateral forces in patella maltracking. Foot orthotics have a role in the setting of functional malalignment secondary to pes pronatus or rear-foot eversion.[12]

Static malalignment can be the source of PFJ pain in the setting of miserable malalignment syndrome. In miserable malalignment syndrome, three universal key features have been described which include femoral anteversion, tibial external rotation, and a lateralized tibial tuberosity.[10,15,16] Patients will present with anterior knee pain and evidence of femoral anteversion or excessive internal rotation and increased tibial external rotation. A "patella" representing a medially rotated patella on standing is seen as a good indicator of increased femoral anteversion.[16] Rotational alignment of the leg can be assessed with computed tomography (CT) or MRI, blocks of images are taken through the hips, knees, and ankles to calculate the angle. The lateralization of the tibial tuberosity is assessed with TT-TG or TT-posterior cruciate ligament (PCL) rather than the Q-angle due to reproducibility. If conservative methods including pharmacological pain management and muscle strengthening fail, then surgery is considered in severe cases. This can involve distal femoral rotational osteotomy and proximal tibial rotational osteotomy.[15,17]

Another cause of anterior knee pain is lateral patellar compression syndrome. Pain is the result of overload and increased pressure on the lateral patellar facet due to pathological soft-tissue restraints. The pain is increased during flexion as the patella moves further lateral within the trochlear groove.[18] X-ray or MRI may demonstrate an increased patella tilt angle or lateral patella shift.[19] Imaging can demonstrate degenerative changes in the lateral side of the patellofemoral compartment as the disease progresses.[20] Surgical treatment options increased arthroscopic release of the lateral patellar retinaculum or lateral phalloplasty depending on the extent and severity of the disease.[18-20]

Hoffa's fat pad impingement

Hoffa's fat pad, also known as the infrapatellar fat pad, is an extra synovial structure located inferiorly to the PFJ. Hoffa's fat pad is highly innervated and vascularised.[21,22] Impingement of the fat pad is caused by trauma or repetitive microtrauma at the tibiofemoral compartment or the lateral aspect of the patellofemoral compartment, this is referred to as Hoffa's disease. A variant pattern called patella tendon-lateral femoral condyle friction syndrome (PTLFCS) involves the superolateral aspect of Hoffa's fat pad and as the name suggests is due to impingement between the patellar tendon and the lateral femoral condyle.[22-24] Presentation is typically anterior knee pain localizing to the infrapatellar region and ROM may be limited with painful knee extension.[22] Appearances on MRI in Hoffa's disease include localized or diffuse fat pad edema, fat pad hypertrophy, fibrosis, and a deep infrapatellar bursitis.[22,23,25] Typically edema in the superolateral aspect of Hoffa's fat pad that can extend centrally is seen on MRI in PTLFCS [Figure 2].[23,24] Conservative treatment options include pain relief, steroid injection, physiotherapy, and patella taping to reduce compression of the fat pad by lifting the inferior pole of the patella.[22] If more definite management is required then arthroscopic partial resection of Hoffa's fat pad can be considered and arthroscopic resection of any fibrotic tissue.[22,25,26]

Hoffa's fat pad ganglion cyst

Ganglia are fluid-filled lesion without a synovial lining that are often associated with the degeneration of an adjacent

Figure 2: A 30-year-old professional classical dancer with anterior knee pain. (a) Axial PDFS image demonstrates a high signal in the superolateral aspect of Hoffa's fat pad (white arrow). This was consistent with the diagnosis of impingement of PTLFCS. (b) Sagittal PDFS image in the same patient with high signal in the superolateral aspect of Hoffa's fat pad (white arrow). PTLFCS: Patella tendon-lateral femoral condyle friction syndrome, PDFS: Proton density fat saturated

structure.[23] A ganglion cyst can arise from many structures within joints including the ligaments, tendon sheath, bursa, subchondral bone, and joint capsule.[27] Ganglion cysts within Hoffa's fat pad were shown to account for 4% of all ganglion cysts within the knee in one study.[28] Ganglia arising from Hoffa's fat is suspected to arise from the synovial alar folds of the fat pad or the anterior cruciate ligament (ACL).[29] They could arise secondary to degeneration of the transverse ligament.[23] The presentation can be with anterior knee pain and a palpable swelling depending on the size of the lesion.[30,31] Ganglion cysts generally follow fluid signal on MRI and therefore will be hypo-to iso-intense on T1 weighted images and hyperintense on T2 weighted images. They may appear as unilocular or multilocular fluid-filled lesions [Figure 3].[27] Arthroscopic or US-guided aspiration can be utilized to treat the cyst with the injection of corticosteroid to reduce the likelihood of recurrence.[32] Arthroscopic or open resection of the ganglia will allow complete removal of the cyst in its entirety.[29,32]

Osgood–Schlatter's disease

Osgood–Schlatter's disease is a traction apophysitis of the tibial tuberosity. Repetitive strain on the quadriceps femoris muscles during physical activity causes stress and microtrauma at the patella tendon insertion on the tibial tuberosity.[33] If physical activity continues then the disease progresses with the repetitive micro-avulsive injuries at the distal patella tendon insertion can lead to fragmentation of the tibial tuberosity.[33,34] Osgood–Schlatter's causes severe anterior knee pain that is worse with particular activities, although it has been found to be self-limiting in 90% of cases.[35] On examination, features include thickening of the distal patellar tendon, swelling, and tenderness at the tibial tuberosity.[33,34] X-rays may demonstrate cortical irregularity at the tibial tuberosity and small fragmented avulsed loose bodies. US appearances include thickening of the distal patella tendon, reduced echogenicity of the tendon, infrapatellar bursitis, and corresponding sonographic appearances of those seen at the tibial tuberosity on X-ray [Figure 4].[36] In addition to patella tendon thickening and avulsed bony fragments, bone marrow edema may be evident at the tibial tuberosity on MRI assessment.[35] Given the frequently self-limiting nature of the disease, conservative management forms the mainstay of treatment. This includes pharmacological pain relief, rest, and physiotherapy. If the disease continues into adulthood then surgical treatment with the removal of bony ossicles or proximal tibial osteotomy to reduce the size of the tibial tubercle.[33,34]

Figure 3: A 19-year-old musical theater dance student with a 2-year history of anterior knee pain. On sagittal PDFS images, a 35 mm multi-loculated ganglion cyst is seen within Hoffa's fat pad (arrow). A small amount of edema is also seen in the adjacent fat (arrowhead). PDFS: Proton density fat-saturated

Patellar tendinopathy

Patellar tendinopathy, also frequently referred to as "jumper's knee," is a clinical syndrome with a high prevalence in athletes participating in activities requiring frequent jumping with a repetitive forceful contraction of the quadriceps.[37] Chronic repetitive tendon overload is thought to cause strain on the deep fibers of the patella tendon at its insertion on the inferior patella pole leading to degeneration.[38] The presentation will often be with chronic or recurrent anterior knee pain exacerbated by activity. Pain will often localize to the patella insertion of the patella tendon with tenderness and swelling.[37]

The proximal third of the patellar tendon is most frequently affected predominantly over the posterior patella tendon fibers due to their insertion on the inferior patella pole. The anterior fibers are less susceptible, as they do not insert on the patella and instead join the quadriceps tendon via the prepatellar quadriceps continuation.[36] US assessment may demonstrate thickening of the proximal patellar tendon with hypoechoic

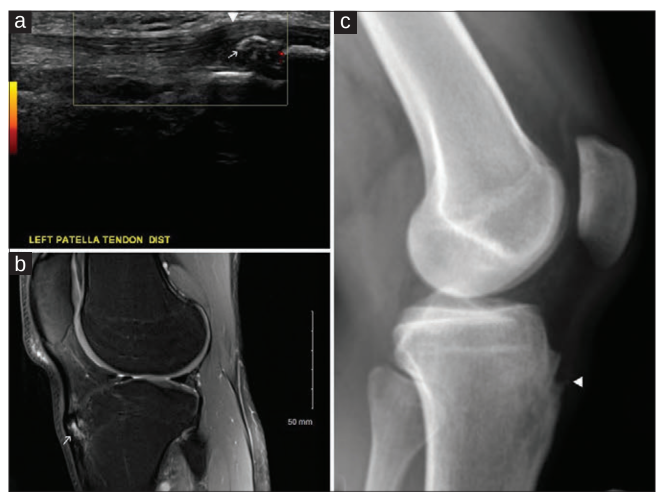

Figure 4: A 17-year-old male contemporary dance student with anterior knee pain. (a) Longitudinal US image of the distal patella tendon insertion. The patella tendon is thickened (arrowhead) with reduced echogenicity and a small ossicle is seen adjacent to the tibial tuberosity (arrow). (b) Sagittal PDFS MRI image. Oedema at the synchondrosis, in the bone marrow at the tibial tuberosity and the adjacent infrapatellar fat (arrow). (c) Irregularity of the cortical surface at the tibial tuberosity is seen on the X-ray (arrow). US: Ultrasound, MRI: Magnetic resonance imaging, PDFS: Proton density fat-saturated

changes in the posterior fibers. Dystrophic calcification within the tendon or fragmentation of the inferior patella pole may be seen in chronic cases.[36] The normal patella tendon is between 4 and 5 mm with >7 mm considered abnormal.[36,37] Increased power Doppler flow can be present in the proximal patellar tendon and is secondary to neovascularisation, this is more likely to be seen in symptomatic individuals.[39] On MRI increased T2 signal may be present in the proximal patella tendon due to edema and increased signal on proton density sequences if mucoid degeneration is present [Figure 5].[37,40] Tendinopathy within the tendon may progress to partial tears or even rupture in severe cases.[36] Nonoperative treatment includes pharmacological pain relief, rehabilitation with eccentric exercise, and extracorporeal shock wave therapy.[38,39,41] Injection with corticosteroids is generally not recommend and the use of other injectates including Platelet-Rich Plasma (PRP), hyaluronic acid, and sclerosing agents is currently experimental.[41] Surgical therapy can be open or arthroscopic with the main principles involving patella tendon tenotomy, debridement of abnormal tendon, and drilling of the inferior patella pole to stimulate repair.[38,39,41]

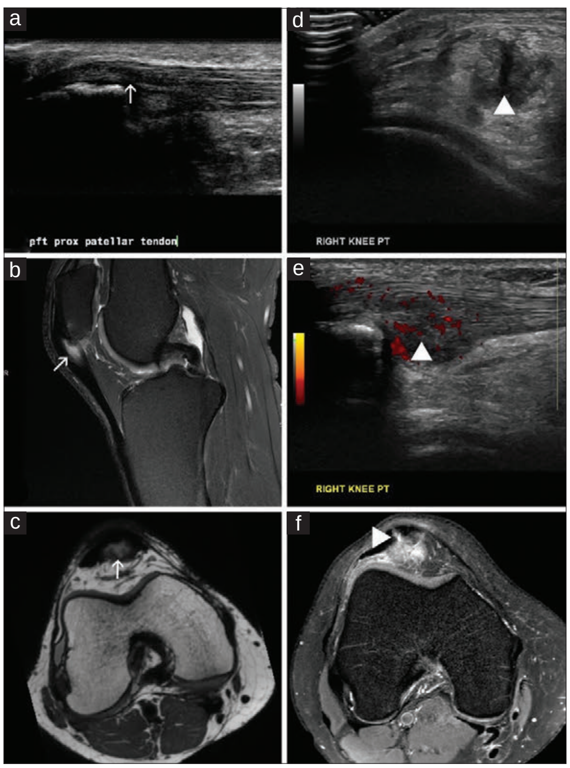

Figure 5: (a-c) A 35-year-old male ex-professional musical theatre teacher with anterior knee pain for 1 year, the patient now is a dance instructor and (d-f). A 20-year-old female musical theatre dance student with 1-year history of anterior knee pain on a background of preceding blunt force trauma to the anterior aspect of the knee. (a) A longitudinal US image of the patella tendon demonstrates reduced echogenicity of the posterior fibers of the proximal patella tendon in keeping with tendinopathy (arrow). (b) Sagittal PDFS MRI image with a corresponding high signal at the same point (arrow). (c) Axial T1 MRI image with high signal in the same location as expected (arrow). (d) A longitudinal US image of the patella tendon shows a split tear of the proximal patella tendon (arrowhead). (e) Increased Doppler signal and reduced echogenicity of the posterior patella tendon fibers suggestive of associated tendinopathy (arrowhead). (f) Axial PDFS MRI images highlight the split tendon tear (arrowhead). US: Ultrasound, MRI: Magnetic resonance imaging, PDFS: Proton density fat saturated

Patellofemoral instability

Patellofemoral instability is defined as a single or multiple episodes of transient lateral patella dislocation.[42] Patients may present following the transient episodes or with anterior knee pain. The stability of the PFJ can be attributed to a combination of anatomical and biomechanical features providing a passive and dynamic constraint for the patella to stay engaged within the trochlear groove during flexion and extension.[43] These include patella and trochlear morphology, patella height, medial and lateral retinacula, skeletal alignment, and the quadriceps muscles.[43] X-ray can be utilized to assess for features of trochlear dysplasia, patella dysplasia, and patella alta.[44] CT allows a good assessment of the patella and trochlear bony morphology, lateralization of the tibial tubercle measured via the tibial tuberosity to trochlear groove distance (TT TG), and lateral patella tilt.[44] Similar cross-sectional assessments can be made on MRI. However, soft-tissue structures and cartilage can be better analyzed on MRI [Figure 6]. This includes the medial patellofemoral ligament (MPFL) and lateral retinacula, quadriceps muscles, and the cartilage of the patellofemoral compartment.[43,44] Kinematic MRI or CT may demonstrate dynamic instability with images taken during flexion and

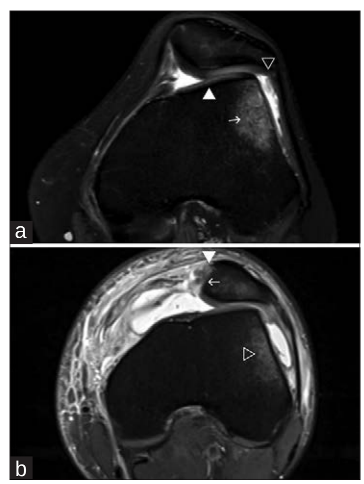

Figure 6: A 27-year-old female contemporary dancer with 2 months' history of anterior knee pain following a twisting injury. (a) The image demonstrates bone marrow edema in the lateral femoral condyle (arrow) due to impaction injury following transient patella subluxation. There is evidence of trochlear dysplasia (block arrowhead) and a lateralized patella (outline arrowhead). (b) Thirty-two-year-old male professional musical theatre dancer with a 3-month history of anterior knee pain following a valgus twisting injury to the knee. A magnetic resonance imaging axial PDFS image highlights features in a transient patella dislocation with lateral femoral condyle edema (outline arrowhead) in addition to injury to the medial patella facet (arrow) and the medial patella femoral ligament (block arrowhead). Evidence of trochlear dysplasia and a lateralized patella is also present in this case. MRI: Magnetic resonance imaging, PDFS: Proton density fat-saturated

extension of the knee. Excessive lateralization of the patella in full extension is a key finding in patellofemoral instability.[42,43] The choice of surgical intervention is dependent on the underlying abnormalities. Surgical options include lateral retinacula release, MPFL reconstruction, distal realignment procedures in the setting of lateralized tibial tubercle and/or patella alta, and trochleoplasty.[44,45]

Cruciate Injury

Anterior cruciate ligament injury

The ACL stabilizes the knee by preventing anterior translation and internal rotation of the tibia with respect to the femur.[46] The ACL arises from the anterior intercondylar eminence of the tibial plateau and attaches to the medial aspect of the lateral femoral condyle.[47] The ACL is most frequently ruptured by a high-intensity pivot-shift mechanism of injury, most commonly seen in athletes playing sports that involve quick changes of direction. In dancers, this will most often be due to a valgus force on an internally rotated knee at the time of landing after a jump.[48] The frequency of ACL injuries is lower in professional dances compared to athletes participating in team sports. The reason for this is attributed to more rigorous jump and balance training in dancers.[49] Other common mechanisms include hyperextension during jumping or high kicks and varus stress on an externally rotated tibia relative to the femur.[47] Clinical tests to asses the integrity of the ACL include the anterior draw or the Lachman tests, which are used to identify abnormal anterior tibial translation, and the pivot shift which can be used to demonstrate abnormal translation and rotational instability.[47] On MRI direct signs of an ACL injury include complete discontinuity of fibers, indistinct fibers or abnormal signals in the ACL [Figure 7].[46] Secondary signs of an ACL injury can be seen on MRI including anterior tibial translation, buckling of the patellar tendon or PCL, uncovering of the medial or lateral meniscal posterior, and visualization of the PCL or lateral collateral ligament on a single coronal image slice.[47] Typical bone marrow edema contusion patterns are seen as dependent on the mechanism of injury.[47] Surgical options include primary repair with suture material or reconstruction with a graft which is frequently a tendon graft such as the patellar tendon, quadriceps tendon, or tendon of a hamstrings muscle. Physiotherapy and rehabilitation are used in surgical patients and those managed conservatively.[50]

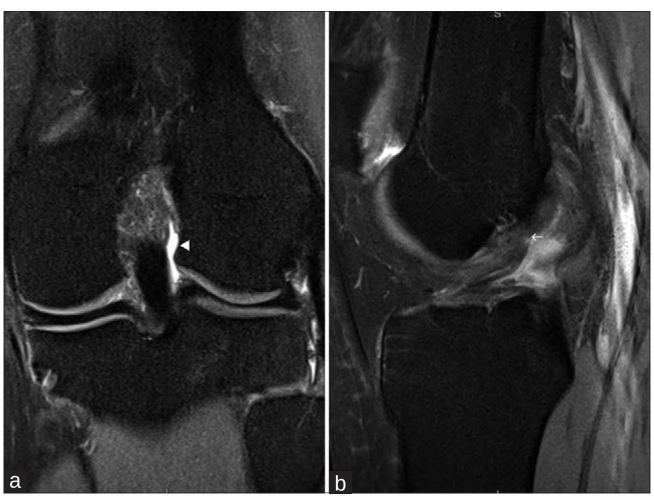

Figure 7: A 22-year-old female professional dancer presented after an awkward landing from a jump during a performance (a and b). (a) Coronal PDFS image with fluid and no intact fibers at the lateral femoral insertion of the ACL – Referred to as the empty notch sign (arrowhead). (b) On a Sagittal PDFS image, the ACL is lax, and no fibers can be seen at the proximal femoral insertion (arrow). ACL: Anterior cruciate ligament, PDFS: Proton density fat-saturated

Lateral Knee Pain

Lateral meniscal tear

The menisci are relatively avascular structures which increase the congruence of the articular surfaces of the knee, aide in shock absorption and load transmission during weight-bearing activities, and provide stability by limiting extreme flexion and extension.[51]

The menisci (medial and lateral) are wedge-shaped semilunar fibrocartilaginous structures with a peripheral superior concave surface abutting the femoral condyle and a flat inferior surface that attaches to the menisci through the anterior and posterior roots. This results in the menisci being thicker peripherally with a tapered-free edge centrally.[52] On MRI the anterior horn, body, posterior horn, and roots will give it a bow-tie appearance on sagittal images and triangular or wedge-shaped on coronal images depending on the location.[52]

In the context of a tear, patients can present with pain localizing to the joint line, swelling, the episodes of the knee giving way, and even locking or clicking.[51] Acute traumatic tears are the result of excessive force to a normal knee and meniscus whilst degenerative tears occur due to normal repetitive forces on a worn-down meniscus.[53] Acute meniscal tears are often associated with injury to other stabilizing structures,

Figure 8: Two dancers with a history of knee pain and locking (a and b). Sagittal PDFS and PD images demonstrate a flipped fragment (arrowheads) adjacent to the lateral meniscal anterior horn as a result of a bucket handle tear. PDFS: Proton density fat-saturated, PD: Proton density

particularly the ACL.[54] MRI is the mainstay imaging modality in the assessment of meniscal tears [Figure 8]. Meniscal tears can be categorized on MRI based on their location and morphology. Meniscal tear types include vertical, horizontal, oblique, radial which occur at the free edge, and complex which comprise multiple morphology types in a single tear.[55] Tears in the peripheral third are called red zone tears due to the good blood supply whilst tears in the more central avascular zone reoffered to as white zone tear.[52] A high fluid signal must be seen on at least two slices and extend to the articular surface to diagnose a meniscal tear.[52] Displaced fragments including bucket handle tears must be identified as they can predispose to locking and grinding.[55]

The management of acute tears is dependent on multiple factors including age, co-morbidities, location, and type of tear.[51] Tears in the red zone can be treated conservatively due to the increased likelihood of healing. However, they also have good outcomes with repair. Partial meniscectomy is more likely to be the treatment choice in white zone tears.[52] In the setting of degenerative tears conservative management with pain relief and physiotherapy will usually be the initial choice. Partial meniscectomy may be considered with progressive meniscal degeneration to debride unstable tears.[53]

Iliotibial band friction syndrome

Iliotibial band syndrome (ITB) friction syndrome is a cause of lateral knee pain due to repetitive activity leading to chronic inflammation in the distal part of the fascia. The pathophysiology is thought to be due to overuse and can usually be improved by modifying biomechanical factors.[56] The ITB runs down the lateral aspect of the knee to insert in Gerdy's tubercle on the lateral aspect of the proximal tibia. The thick fascia is separated from the lateral femoral condyle by the lateral synovial recess. This extension of the knee joint synovium can also become inflamed and is likely to contribute to the pain.[57] MRI appearances can include soft tissue edema between the ITB and the lateral femoral condyle, thickening of the ITB, fluid within an adventitial bursa, and reactive edema in the lateral femoral condyle.[58] Mild edema can sometimes be seen in the fat underlying the ITB in asymptomatic patients and the correct clinical context is imperative.[58] First-line treatment predominantly consists of Non-Steroid Anti-Inflammatory Drug (NSAIDs), rest, stretching, and strengthening exercises followed by steroid injections. Surgery can be considered in refractory cases and options include ITB release, IT bursectomy, and lateral synovial recess resection.[56,58]

Medial Knee Pain

Medial meniscal tear

Meniscal tears have been discussed earlier with regard to lateral knee pain [Figure 9]. The medial meniscus is thought to be more prone to tearing due to its reduced mobility as a result of its attachment to the medial collateral ligament (MCL) and the deep posterior capsule.[59] In addition, tears can occur at the posterior medial meniscocapsular junction and are termed Ramp lesions. These occur in higher frequency in conjunction with ACL tears and the repair of these lesions during ACL reconstructions shows improved outcomes.[60]

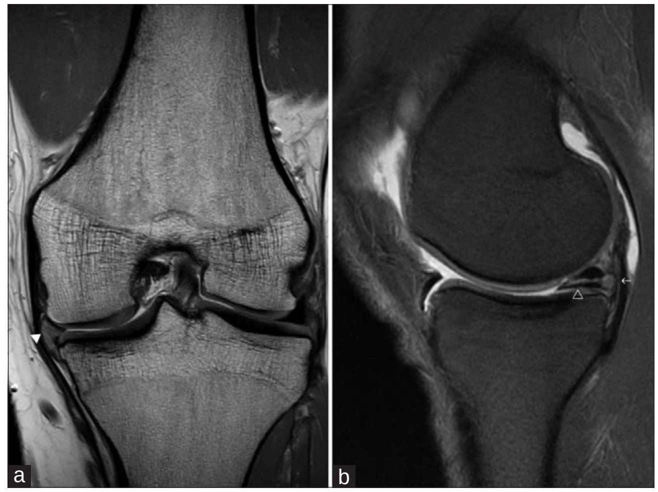

Figure 9: Twenty-three-year-old male contemporary dancer with left knee pain, locking and the knee giving way. A preceding history of pain and swelling was noted following an episode of trauma with an awkward landing whilst dancing. (a) The coronal PD image shows abnormal signal in the medial meniscus (block arrowhead). (b) Sagittal PDFS images demonstrate a horizontal tear in the posterior horn of the medial meniscus (outline arrowhead) and an adjacent parameniscal cyst (arrow). PD: Proton density

Medial collateral ligament

The MCL is the primary static stabilizer of the medial side of the knee joint resisting valgus, rotational, and horizontal translation stress.[61] It is made of the superficial MCL and deep MCL fibers. The superficial fibers extend from the medial femoral epicondyle to the medial condyle of the tibia. The deep component is made of two parts the meniscofemoral and meniscotibial ligaments.[61] The MCL is one of the most common knee ligament injuries and frequently occurs in conjunction with injuries to other knee ligamentous structures[62] Injury commonly occurs due to a valgus force applied to the lateral side of the knee.[61] Clinical examination can allow the grading of MCL injuries. A Grade 1 injury involving a few superficial fibers will demonstrate localized tenderness and no instability, Grade 2 injury with high-grade disruption of superficial MCL fibers and intact deep MCL will again have no instability however broader tenderness, and Grade 3 injuries involve disruption of the superficial and deep MCL will demonstrate instability on valgus stress.[61] Stress radiographs can demonstrate increased gapping of the medial side of the knee that also increases further on flexion.[63] A Pellegrini–Stieda lesion is a calcified lesion adjacent to the medial femoral condyle and is a sign of an old injury to the proximal MCL and this can be identified on X-ray.[64] A Pellegrini–Stieda lesion is a calcified lesion adjacent to the medial femoral condyle that forms following trauma to the proximal MCL, likely due to a previous avulsion injury [Figure 10].[64] On MRI in Grade 1, abnormal signals will be seen in the soft tissue around the superficial MCL and changes to the ligament itself may not be present. In a Grade 2 injury, the abnormal signal is seen in the ligament and some disrupted fibers may be identified however no full-thickness tear will be present. In a Grade 3 injury, a full-thickness tear of the superficial and deep MCL is likely to be evident.[65] The superficial MCL is a highly vascularised structure therefore successful healing is frequently seen with nonoperative management.[63] In the acute setting, a Grade 1 or 2 is managed conservatively with rehabilitation and pharmacological pain relief. An isolated acute Grade 3 injury is also managed conservatively. However, if it occurs in conjunction with an ACL injury, the ACL may be repaired after rehabilitation for the MCL injury.[62,63] MCL surgical repair is often considered in chronic Grade 3 injuries (3 months +) due to persistent instability or in the context of a complex multi-ligamentous injury requiring surgery.[62,63,66]

Pes anserinus bursitis

The tendons that make up the pes anserinus are the sartorius, semitendinosus, and gracilis. They attached to the medial aspect of the knee. The pes anserinus bursae are found between the tendons and the superficial MCL.[67-69] Pes anserinus can be frequently seen due to repetitive friction over the bursa, particularly in runners.[67,69] Presentation is often with knee pain and tenderness over the inferomedial aspect of the knee.[68] US features of pes anserinus bursitis include fluid in the bursa with thickening of the tendons and loss of normal fibrillar echogenicity seen if tendinopathy is present, although these appearances do not have to be seen for a clinical diagnosis to be made. MRI findings can be fluid in the bursa and surrounding soft tissue edema.[70] Pes anserinus bursitis will often resolve with rest and NSAIDs. US-guided fluid aspiration and steroid injection can be considered in refractory cases.[69,70]

Figure 10: A 25-year-old professional street dancer with a 3-month history of insidious onset left knee pain after a period of dancing. A traumatic injury occurred 1 month before the onset of the chronic pain. This involved a valgus stress on the knee when landing from a jump, immediate pain, and swelling promptly resolved. The AP view on the X-ray demonstrates a calcified Pellegrini–Stieda lesion (arrow) which is likely to be secondary to a proximal MCL injury at the time of the initial fall 4 months prior to the X-ray. MCL: Medial collateral ligament, AP: Anteroposterior

Osteoarthritis

Patellofemoral joint degeneration

The PFJ is the articulation of the patella with the trochlear groove of the femur. Patellofemoral osteoarthritis can be identified in isolation or the setting of global knee osteoarthritis. Patellofemoral can present as anterior knee pain with features of stiffness, joint line tenderness, and reduced mobility.[71] Imaging features have been well document and classical X-ray features are loss joint space, marginal osteophytes, subchondral sclerosis, and cysts. In addition, MRI can identify cartilage defects and subchondral bone marrow edema [Figure 11].[72] Conservative management options include physiotherapy, NSAIDs and intra-articular steroid injections.[71] Surgical options are broad and can address the correction of underlying predisposing factors, treatment of isolated cartilage defects, or arthroplasty.[71] Examples of surgical options for the treatment of isolated articular cartilage damage are microfracture, chondrocyte transplantation, and osteochondral grafts.[73]

Other

Osteochondral injury

An osteochondral injury is a defect in the articular hyaline cartilage with associated injury of the subchondral bone. An osteochondral defect can occur secondary to acute trauma, osteochondritis dissecans, Avascular Necrosis (AVN), subchondral insufficiency fracture, and osteoarthritis.[74] A common site for cartilage damage is the weight-bearing surfaces of the medial and lateral femoral condyles and this

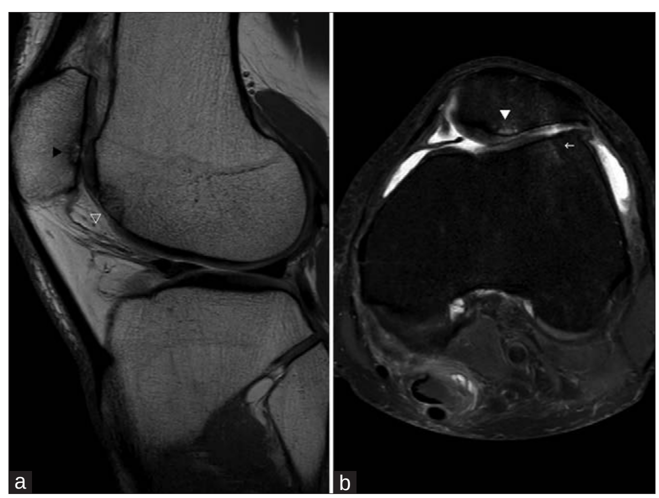

Figure 11: A 64-year-old keen recreational dancer with a 5-month history of bilateral anterior knee pain without any preceding traumatic event. (a and b) Sagittal PD and axial PDFS images highlight multiple areas (arrowheads and arrow) of full-thickness cartilage loss and associated subchondral edema on the retro patellar and trochlear surfaces. PD: Proton density, PDFS: Proton density fat-saturated

can be associated with significant pain.[75] However, given the increased predisposition for dancers to have PFJ issues, this may be a more likely site, particularly in the context of adult Osteochondral Defect (OCD) or an acute traumatic episode. MRI is utilized for the identification of a defect and the grading of its stability [Figure 12]. Grade 1 lesion will have high T2 signal rim at the interface of the lesion and the adjacent bone, Grade 2 will demonstrate tiny fluid-filled cysts deep to the lesion, Grade 3 the high T2 signal rim will extend through the articular cartilage, and in Grade 4 fluid will fill the gap of a displaced lesion.[74] Treatment varies depending on the severity and location of the defect but can be challenging in active men and women.[76] Conservative treatment includes activity modification, NSAIDs, pain relief, and physiotherapy.[77] Osteochondral autograft transplantation, autologous chondrocyte transplantation, and microfracture are some of the most common surgical treatments used for osteochondral defects.[76]

Summary

Dancers are prone to a wide range of knee pathologies with anterior knee pain being the most common in our cohort (111 patients out of 197). Within the category of anterior knee pain, PFJ pain accounts for the most encountered issues with 69 patients. This could be related to the dynamic nature of dance given the association of PFPS with activities involving running, jumping, and squatting.[14]

In the remaining cases, the numbers are spread between the different locations of the knee. An anatomy-based approach with regard to the site of pain can be useful in identifying any potential abnormality. Knowledge of the radiological appearances of the most frequently seen knee abnormalities in dancers will aid in prompt and correct diagnosis.

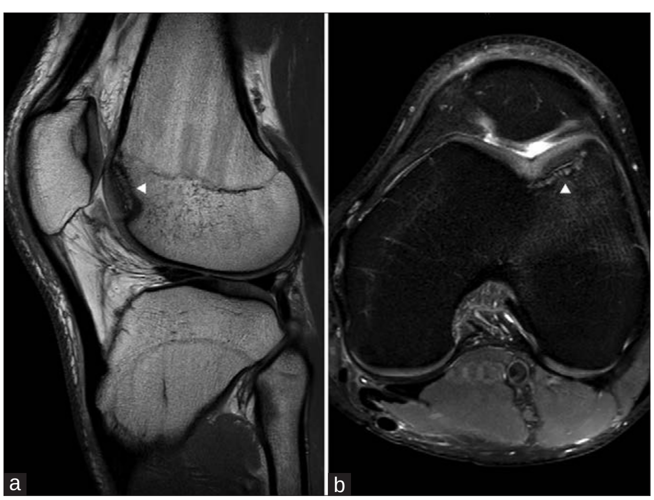

Figure 12: (a and b) A 18-year-old male dance student with a 3-year history of anterolateral knee pain. Sagittal T1 and axial PDFS images show an osteochondral lesion with fluid signal undercutting the defect and subchondral cysts in the bone (arrowheads). PDFS: Proton density fat-saturated

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Conflicts of interest

There are no conflicts of interest.

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Early Changes in the Bone Mineral Density on Dual-energy X-ray Absorptiometry Scan of Patients Undergoing Primary Cemented Total Knee Arthroplasty: A Prospective Cohort Study

Aamna Athwal, Pankaj Mahindra[1], Rajnish Garg[1], Punit Tiwari[2], Harmeet Kaur[3], Sandeep Singh Jaura[2]

Department of Orthopaedics and Trauma Surgery, TORT Centre, Ninewells Hospital and Medical School, University of Dundee, Dundee, United Kingdom, [1]Department of Orthopaedics, Dayanand Medical College and Hospital, Ludhiana, [2]Department of Orthopaedics, Maharishi Markandeshwar Medical College and Hospital, Solan, Himachal Pradesh, [3]Department of Radiodiagnosis, All India Institute of Medical Sciences, Bathinda, Punjab, India

Abstract

Background: The known risk factors of osteoarthritis (OA) knee are aging and obesity while the risk factors of osteoporosis are aging and low body weight, so the relationship between all three is complex. Currently, the dual-energy X-ray absorptiometry (DXA) test is the gold standard in osteoporosis diagnostics. Many epidemiologic studies have revealed increased bone mineral density (BMD) in individuals with OA knee. The impact of total knee arthroplasty (TKA) on BMD levels is not fully understood. Concern has been raised regarding the increased risk of femoral and spine fractures early after TKA. Hence, we conducted this study to measure the BMD changes in the hip and spine in patients receiving TKA. **Materials and Methods:** It was a prospective interventional cohort study conducted from December 2018 to December 2020. The study included 43 patients admitted for elective TKA after applying the relevant inclusion and exclusion criteria. Patients were analyzed with DXA scans both preoperatively and 6 months postoperatively. **Results:** When we studied all the patients as one single sample, the initial observation was that at the 6-month follow-up, the patients showed a statistically significant improvement in the femur BMD score while the change in spine BMD was statistically insignificant. However, when subsets of the study sample, i.e. preoperatively normal, osteopenic, and osteoporotic patients, underwent further analysis, we found that out of 18 patients having normal BMD preoperatively, one patient developed osteopenia and another developed osteoporosis upon postoperative follow-up DXA scan. Similarly, one out of the eight patients, having osteoporosis preoperatively, improved a grade to osteopenia upon postoperative follow-up DXA scan. However, these changes were not statistically significant. **Conclusions:** we conclude that there is no statistically significant change in both the femur and the spine BMD at least 6-month follow-up postprimary TKA.

Keywords: BMD, DXA, DEXA, total knee arthroplasty, total knee replacement

Introduction

Osteoarthritis (OA) is believed to be the most common chronic joint disease of the knee.[1] It is a cartilage disease with multifactorial etiologies which include an interplay between systemic and local factors. Adolescent athletes are more likely to get OA early if they participate in sports, get a joint injury, are obese, or have a genetic predisposition to it.[2] OA is influenced by several factors, including advanced age, female gender, excess weight and obesity, knee injury, repeated motion of the joints, bone density, muscle weakness, and joint laxity.[3] Among the various factors, the association between OA and bone mineral density (BMD) is complex and of an inverse type. Osteoporosis and OA are common diseases in women over the age of 65, and the aging population in recent years has increased the number of patients with both diseases. As aging and low body weight are the risk factors of osteoporosis while the risk factors of

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Address for correspondence: Dr. Punit Tiwari, Department of Orthopaedics, Maharishi Markandeshwar Medical College and Hospital, Kumarhatti, Solan, Himachal Pradesh, India. E-mail: punit_tiwari28@yahoo.com

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OA knee are aging and obesity, the relationship between all three is complex.

Currently, dual-energy X-ray absorptiometry (DXA) of the lumbar spine or femoral neck is the gold standard for diagnosing osteoporosis. The result is expressed as a standard deviation (SD) from the peak BMD, called the *T*-score. While the *Z*-score is the SD from the mean BMD value for a given age.[4] Cross-sectional data from large epidemiological studies show an increased BMD in people with knee OA.[5-7] When compared to patients with normal knee radiographs, individuals with specific radiographically documented abnormalities of OA knee have higher hip, total-body, and lumbar spine BMDs.[8]

In a study conducted by Hart *et al*., in comparison to women without the incident disease, the 95 women with incident knee osteophytes had a greater baseline spine BMD (1.01 g/cm^2 against 0.95 g/cm^2, or 6.3%; $P = 0.002$) and hip BMD (0.79 g/cm^2 vs. 0.76 g/cm^2, or 3.9%; $P = 0.02$). These results confirm that BMD is higher and comparable in magnitude to that seen in cross-sectional studies involving women who develop incident knee OA, as defined by osteophytes.[5] As per the Framingham study, high BMD and BMD gain may be linked to an increased risk of incident knee OA but a decreased risk of radiographic knee OA progression.[9]

Although the association between low BMD and high fracture risk is well established in the literature, the impact of total knee arthroplasty (TKA) on BMD score is not fully understood. Concern has been raised regarding the increased risk of hip and spine fractures early after TKA.[10-13] Studies which compared BMD in normal, osteoporotic, and osteopenic patients who underwent TKA are sparse in the literature. Studies on changes in axial BMD in patients undergoing TKA for severe OA are scarce, and there is no consistent consensus.

Hence, we undertook this study to measure the BMD changes in the hip and spine in patients undergoing TKA. Our null hypothesis was that there is no difference in axial BMD values pre- and post-TKA.

Materials and Methods

It was a prospective interventional cohort study conducted at the department of orthopedics of our tertiary-level health-care center and medical college from December 2018 to December 2020. The study included 43 patients admitted for elective TKA after applying the relevant inclusion and exclusion criteria. Patients were analyzed after 6 months.

Inclusion criteria

Patients who underwent primary TKA for knee arthritis were included in the study.

Exclusion criteria

- Patients who underwent revision knee replacement previously
- Patients who have undergone any previous surgery on the knee joint
- Patients having congenital deformity of one or both the lower limbs
- Patients having pathological fractures or tumors around the knee joint
- Patients with concomitant hip or spine deformities were excluded from the study.

The study of Dincel *et al*.[14] observed that the pre- and postoperative *T*-scores of the L1–L4 section were −0.6934 and −0.6763, respectively. Taking it as a reference and assuming a SD of 0.03, the minimum sample size required for 90% power of the study and a 5% level of significance is 33 patients. Assuming a 20% loss to follow-up, the total size of the sample to be taken is 42.

The formula used is:

$$N = \frac{(\text{standard deviation})^2}{(\text{mean difference})^2} \times \left(Z_\alpha + Z_\beta\right)^2$$

where Z_α is the value of Z at a two-sided alpha error of 5% and Z_β is the value of Z at a power of 90% and the mean, the difference is the difference in mean values of pre and post.

Calculations:

$$N = \frac{(0.03)^2 \times (1.96 + 1.28)^2}{(0.0171)^2}$$

=32.31 = 33 (approximately)

Taking lost to follow-up as 20%, $n = 33/8 = 41.25 = 42$ (approximately).

Ethical clearance was obtained from the institutional ethics committee. Written informed consent was obtained from the patients. All patients in this study were operated on by the second author using the same brand implant PFC modular knee system, DePuy, USA.

The complete demographic, personal, and clinical history was taken and filled in the study pro forma. Patients were assessed preoperatively using a pro forma having two parts – to be filled by the clinician and the patient, respectively, BMD at the lumbar and hip region was measured by DXA in the supine position. The GE Lunar iDXA (GE Healthcare Lunar, Madison, WI) was used in the DXA measurements. Postoperative BMD was measured by the same machine in the same manner. Osteoporosis was defined by a *T*-score of -2.5 or less and osteopenia was defined by a *T*-score between -2.5 and -1 at the lumbar, the femoral neck, and total hip (TH) region [Table 1] whichever was lowest according to the World Health Organization International reference standard.[15] Patients were re-assessed during a 6-month follow-up period. The outcome measured the change in the BMD.

Statistical terms such as range, mean ± SD, frequencies (number of cases), and relative frequencies (percentages) were used to describe data. A Kolmogorov–Smirnov test was used to determine whether the data were normally distributed. The Wilcoxon rank test for nonparametric data was used to compare quantitative variables between the study groups. The McNemar–Bowker test was used to compare categorical data. A probability value ($P < 0.05$) was considered statistically significant. The Statistical Package for the Social Science, SPSS 21 version (SPSS Inc., Chicago, IL, USA) statistical program for Microsoft Windows, was used for statistical calculations. A probability value ($P < 0.05$) was considered statistically significant. All statistical calculations were done using SPSS (Statistical Package for the Social Science) SPSS 21 version statistical program for Microsoft Windows.

Results

The demographic and clinical characteristics of the study population are outlined in Tables 2 and 3. Given the primary aim to understand the changes in BMD, all patients underwent a DXA scan which showed the BMD score and a standardized *T*-score based on which it was known that 18 (41.9%) patients had normal BMD, 17 (39.5%) had osteopenia, and 7 (18.6%) had osteoporosis. In our study, when we studied all the patients as one single sample, the initial observation is that at the 6-month follow-up, the patients show a statistically significant improvement in the femur BMD score [Table 4] while the change in spine BMD is not statistically significant [Table 5]. Further statistical analysis of subsets of the study sample, i.e. preoperatively normal, osteopenic, and osteoporotic patients, and their preoperative femur and spine BMD and *T*-scores and those values at postoperative follow-up were done. The results are summarized in Tables 6-8. Out of 18 patients having normal BMD preoperatively, one patient developed osteopenia and another developed osteoporosis upon postoperative follow-up DXA scan. Similarly, one out of the eight patients, having osteoporosis preoperatively, improved a grade to osteopenia upon postoperative follow-up DXA scan. None of the total 43 patients was lost to follow-up, and none of them sustained a hip or spine fracture during the study period.

Discussion

Various hypotheses have been put forward in the literature for the increased incidence of hip and spine fractures post-TKA. These range from simply the increased level of activity post-TKA to the predisposing osteoporosis developed in the pre-TKA arthritic stage with hampered mobility. The sudden correction of the mechanical deformity post-TKA and altered kinematics with constrained implants are also the purported culprits.[10-13] It has also been proposed that the BMD decreases immediately post-TKA because of immobilization and due to the bone remodeling taking place resulting from the stress-shielding effect of the femoral component.[14] As osteoporosis is both preventable and treatable, it merits an investigation post-TKA.

Table 1: World Health Organization criteria of osteoporosis and osteopenia according to *T*-score

Stage	*T*-score value
Normal	>−1
Osteopenia	−1–−2.5
Osteoporosis	<−2.5
Severe osteoporosis	<−2.5±1 fragility fracture

Table 2: Demographics of study participants

Parameters	*n*	Mean±SD	Range
Age (years)	43 (31 female +12 male)	61.55±9.27	37.2–80.9
Weight (kg)	43	76.93±13.2	50–104
Height (cm)	43	157.4±9.07	135–177
ROM right (°)	43	93.95±5.41	80–100
ROM left (°)	43	94.42±5.02	90–100
Serum Vitamin D level	42	26.17±13.83	7.29–81.97
Serum calcium level	42	8.34±0.91	5.4–10.1
AP spine BMD score	43	1.12±0.19	0.71–1.50
AP spine *T*-score	43	−0.61±1.52	−3.70–2.4
borderline femur BMD score	43	0.9±0.22	0.017–1.32
Borderline femur *T*-score	43	−0.9±1.26	−2.7–1.6
Post-ROM right (°)	43	115.35±8.82	90–120
Post-ROM Left (°)	43	116.28±8.74	90–130
Post-AP spine BMD score	42	1.13±0.18	0.766–1.503
Post-AP spine *T*-score	42	−0.49±1.47	−3.5–2.4
Postborderline femur BMD score	42	0.94±0.18	0.657–1.32
Postborderline femur *T*-score	42	−0.65±1.3	−2.7–1.7

ROM: Range of motion, BMD: Bone mineral density, SD: Standard deviation, AP: Anteroposterior

Table 3: Distribution of age of study subjects

Age (years)	Number of cases
<60	20
61–70	16
>70	7
Total	43

DXA is an important diagnostic tool for detecting osteoporosis in patients with OA and undergoing TKA. It serves as a promising supplement to x-ray scoring methods.[16] As per the International Society for Clinical Densiometry, the *T*-score is used in the case of men aged 50 or more and women after menopause, and the Z-score is used in the case of men below 50 years of age and women before menopause. A major limitation of the DXA scan is that it tells us about only BMD without taking into account the microstructural pattern of bone. The BMD may be falsely increased in case of the presence of degenerative lesions such as osteophytes, sclerosis, or

Table 4: Change in femur scores of the total study sample in dual-energy X-ray absorptiometry scan at 6 months

Variables	Mean±SD		*t*	*P*	Difference, mean±SD
	Pre	Post			
Borderline femur BMD score	0.90±0.22	0.94±0.18	−2.049	0.047	−0.04±0.13
Borderline femur *T*-score	−0.88±1.26	−0.65±1.30	−2.299	0.027	−0.23±0.66

BMD: Bone mineral density, SD: Standard deviation

Table 5: Change in spine scores of the total study sample in dual-energy X-ray absorptiometry scan at 6 months

Variables	Mean±SD		*t*	*P*	Difference, mean±SD
	Pre	Post			
AP spine BMD score	1.12±0.19	1.13±0.18	0.906	0.370	0.05±0.33
AP spine *T*-score	−0.61±1.52	−0.49±1.47	−0.986	0.330	−0.07±0.46

BMD: Bone mineral density, SD: Standard deviation, AP: Anteroposterior

Table 6: Preoperatively normal patients' dual-energy X-ray absorptiometry findings at 6-month follow-up

	Preoperatively normal patients (18)		
	Mean±SD		*P*
	Preoperative	Postoperative	
AP spine BMD score	1.27±0.13	1.26±0.13	0.803
AP spine *T*-score	0.60±1.08	0.64±1.03	0.761
Borderline femur BMD score	1.08±0.13	1.12±0.10	0.086
Borderline femur *T*-score	0.29±0.82	0.59±0.78	0.128

Wilcoxon test. BMD: Bone mineral density, SD: Standard deviation, AP: Anteroposterior

Table 7: Preoperatively osteopenic patients' dual-energy X-ray absorptiometry findings at 6-month follow-up

	Preoperative osteopenic patients (17)		
	Mean±SD		*P*
	Preoperative	Postoperative	
AP spine BMD score	1.08±0.09	1.09±0.08	0.187
AP spine *T*-score	−0.89±0.75	−0.76±0.70	0.117
Borderline femur BMD score	0.79±0.21	0.85±0.07	0.211
Borderline femur *T*-score	−1.47±0.58	−1.38±0.50	0.156

Wilcoxon test. BMD: Bone mineral density, SD: Standard deviation, AP: Anteroposterior

compression fractures in the examined areas and hence the osteoporosis may not be revealed in the DXA test, rendering the results at odds with the clinical profile.[17]

Studies on BMD changes in the periprosthetic area following total joint replacement are numerous, but there are few studies on BMD changes in the axial bone following total joint replacement in patients with OA. Moreover, these too have reached different conclusions suggesting increased, decreased, or unchanged BMD post-TKA.

The spine BMD is valuable as its measurements denote the status of the bone density away from the joint replacement site. As osteoporotic fractures of the spine and hip are not infrequent, it is worth studying the postoperative changes in the findings of the DXA scan. Preemptive measures can be planned based on the knowledge gained in this study.

Beaupre *et al*. showed a negative change in BMD values of the spine in the 1st postoperative year compared to the preoperative period.[18] In the study by Dincel *et al*., the *T*- and *Z*-scores of the spine (L1–L4) were observed to have a marginally positive trend with a negligible statistical difference ($P \geq 0.05$).[14] Their observations are in concurrence with our results which showed that TKA patients had an insignificant change in the spine BMD at 6-month follow-up after the surgery.

In the 1st year after knee replacement, there is a noticeably higher incidence of hip fractures in the literature. Hopkins *et al*. conducted a BMD study on TKA patients and found that at 6 months, the ipsilateral neck of femur and TH BMD, as well as the contralateral leg lean tissue mass, were significantly lower in the TKA group.[19] This bone loss at the hip could be the reason for an increased hip fracture risk in the year following surgery. Kim *et al*. studied 48 patients and found that at 1 month and 3 months after TKA, BMD in the femoral neck, trochanter, and TH areas was significantly lower than preoperative BMD.[20]

Few studies though found an improvement in the BMD of the femur postsurgery, but the values failed to reach statistical significance. The study by Dincel *et al*. showed that the *T*- and *Z*-scores of the proximal femur showed a slight improvement postoperatively (preoperative and postoperative *T*-score was −1.5763 and −1.5513; *Z*-score was −0.0461 and −0.0632), but the change was not statistically significant ($P \geq 0.05$).[14] Similarly, Ishii *et al*. found that, despite a predicted age-related loss of 4% over 2 years, 45% of operative hips and 59% of nonoperative hips had BMD greater than preoperative levels, the statistical significance of which was not shown.[21] In another study by Hahn and Won, there were no significant differences in femur neck and TH BMD between preoperative and 1-year postoperative measurements. One year BMD being 0.695 ± 0.086 and 0.762 ± 0.102 as compared to preoperative values of 0.694 ± 0.082 and 0.755 ± 0.099.[22] In our study, we found that the course of preoperative to postoperative BMD in TKA patients is not predictable. It may either remain the same, improve, or even worsen.

Post-TKR, it was seen that the femur BMD score of patients improved significantly from 0.90 ± 0.22 to 0.94 ± 0.18 ($P = 0.047$) with a femur *T*-score improvement

Table 8: Preoperatively osteoporotic patients' dual-energy X-ray absorptiometry findings at 6-month follow-up

Preoperatively osteoporotic patients (8)			
	Mean±SD		*P*
	Preoperative	Postoperative	
AP spine BMD score	0.85±0.09	0.85±0.08	0.920
AP spine *T*-score	−2.75±0.71	−2.71±0.67	0.768
Borderline femur BMD score	0.71±0.04	0.71±0.04	0.982
Borderline femur *T*-score	−2.39±0.32	−2.03±0.78	0.261

Wilcoxon test. BMD: Bone mineral density, SD: Standard deviation, AP: Anteroposterior

from -0.88 ± 1.26 to -0.65 ± 1.30 postoperatively ($P = 0.027$). Overall, the spine BMD score did not show a significant improvement, 1.60 +- 3.07 in preoperative versus 1.13 +- 0.18 at 6 months operatively ($P = 0.327$). However, these results were obtained if statistical tests were applied to study subjects as a whole. When the DXA scan results of preoperatively normal, osteopenic, and osteoporotic subjects were statistically analyzed postoperatively, the difference was found to be insignificant.

Our study is not without limitations. Its results must be interpreted with caution. The sample size was small, and the study was from a selected socioeconomic status visiting our hospital in a private setup. A study with a larger sample, from diverse socioeconomic statuses, and a longer follow-up could have yielded results that could be generalized. All patients were given the calcium and Vitamin D supplementation postoperatively in a uniform dosage irrespective of their preoperative BMD levels though none of them were given the bisphosphonates. This could have had bearing on our study results.

Conclusions

From the observations of our study, we failed to reject the null hypothesis stated in the beginning and conclude that there is no statistically significant change in both the femur and the spine BMD at least at 6-month follow-up post-primary TKA.

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Conflicts of interest

There are no conflicts of interest.

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Do they Feel Better When they Walk Better? 3D Gait Analysis Study in Total Knee Arthroplasty for Indian Osteoarthritic Knees

Sanket Tanpure, Ashish Phadnis, Taral Nagda, Chasanal Rathod, Ajay Pandit Chavan[1], Mayuri Gad[1]

Department of Orthopaedics, Jupiter Lifeline Hospital, Thane, [1]Jupiter Gait Lab, Jupiter Lifeline Hospital, Thane, Maharashtra, India

Abstract

Background: Osteoarthritis (OA) is a leading cause of disability in the elderly population. Gait analysis is a widely used tool to measure functional outcomes after total knee arthroplasty (TKA). This study aimed to assess the gait pattern and influence of TKA in patients with osteoarthritic knees. **Materials and Methods:** Preoperative and postoperative gait analysis was carried out on patients with grade 4 OA knee undergoing TKA. Sequential 33 adults (45 knees) with a mean age of 68.4 ± 5.8 years were studied. Gait analysis was carried out in Jupiter gait lab with 9 Qualisys Oqus cameras system and Qualisys track manager. Kinematic data were processed using Visual 3D C-Motion Software during a minimum of 6 walks across the walkway. **Results:** A significant difference in temporospatial parameters (gait speed, Cadence, step time, step length, stride width, stride length), joint kinematics in the sagittal plane (pelvis, hip, knee, ankle), coronal plane (pelvis, hip, knee, ankle), transverse plane (hip, knee) and motion analysis profile of knee (flexion/extension), ankle (dorsiflexion/plantarflexion), and hip (adduction/abduction). A significant difference was observed in the oxford knee score (OKS), Short Form 12, and knee society score. **Conclusion:** 3D gait analysis is a good tool to document and compare gait changes in patients undergoing TKA. Recent advances in surgical techniques and improvements in prosthesis design are important factors for better functional outcomes. Our results may be used by clinicians, physiotherapists, or researchers as a reference for integrated aspects for the development of TKA implant designs and improving functional outcomes.

Keywords: 3D gait analysis, osteoarthritic knee, total knee arthroplasty

Introduction

The growing number of arthroplasties results from various factors that include the aging population, increasing prevalence of arthritis, and increase in the obese population.[1,2] The leading cause of arthroplasty procedure is osteoarthritis.[3,4] Total knee arthroplasty (TKA) is considered the most successful surgery even after 15 years. Moreover, implant survival is more than 95%.[5-7] Various reports suggest that TKA improves functional status and it relieves pain in the operated knee.[8]

In 1880, German surgeon Theophilus Gluck performed the first replacement in history with an ivory prosthesis fixed with bone by plaster.[9] There was no recognizable progress until 1973 when Insall *et al.* proposed a prototype of a modern knee prosthesis that comprised a metallic femoral component, fixed plastic tibial, and patellar component.[10]

It is important to know whether gait is normal after total knee replacement (TKR). Normal gait is defined as the walking pattern exhibited by healthy adults who do not have any lower extremity injuries or surgeries and are of a similar age to those with arthroplasty.

Gait analysis is the study of human locomotion, augmented by instrumentation to measure body kinematics and the activity of muscles. It is a high-quality motion analysis system that provides patterns not only in normal healthy participants but also in those having pathological and neurological disorders such as stroke and cerebral palsy.[11,12] Several recent studies demonstrated the importance of analysis to guide rehabilitation training.[13,14]

Gait analysis comprises temporospatial parameters, joint kinematics, gait profile score (GPS), and motion analysis

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Address for correspondence: Dr. Sanket Tanpure,
Department of Orthopaedics, Jupiter Lifeline Hospital,
Thane-400 601, Maharashtra, India.
E-mail: sankettanpure55@gmail.com

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profile (MAP). GPS and MAP are the collective data of the gait variable score (GVS). Nine relevant kinematic variables combine to form MAP. The root mean square of the average GVS is GPS.[15] Gait speed is the most commonly used reference value in temporospatial parameters to comment on gait performance.

The drawback of using gait analysis in the clinical setting is that it is time-consuming and expensive. The interpretation of the data from gait analysis, which is frequently presented as graphs of different joint kinematic factors, presented another challenge.

The majority of preoperative and postoperative investigations in western populations only focused on a single set of gait parameters. Since height, femoral hip offset, rotations, and physical anthropology differed from those of people of Caucasian origin, no such research has been conducted in the Asian community.[16] Therefore, our study aimed to compare preoperative and postoperative gait parameters (temporospatial parameters, joint kinematics, GPS, and MAP) along with functional satisfaction outcomes by oxford knee score (OKS), Short Form 12 (SF 12), and knee society score (KSS).

Materials and Methods

Data were collected from 33 patients (45 knees) suffering from osteoarthritis of the knee having a mean age of 68.45 ± 5.83 years [Table 1]. Preoperative gait analysis was done a day before surgery. Sequential nonrandomized gait analysis was done in surgery-opted patients having Kellgren–Lawrence radiographic osteoarthritis classification stage 4 and knee pain for more than 3 years. All patients have varus deformities. Postoperative radiographs are taken for comparison but not included in the study. Postoperative gait analysis was done at 180 ± 20 days from surgery. Preoperative OKS, SF 12, and KSS were taken on the day of admission and postoperative score at 3 months after surgical intervention. In all patients, the same implant was used (Zimmer Biomet posterior stabilized). The duration of the study was 3 years. Patients with Kellgren–Lawrence stage 4 with varus knees were included in the study. Patients with revision knee replacement, any previous limb surgery, inflammatory arthropathy, and valgus knees are excluded from the study.

Procedure

Twenty reflective markers + four cluster markers (4 markers in each) with a total of 36 reflective markers (8 static and 28 dynamics including cluster markers) of diameter 16 mm were stuck to the anatomical bony landmarks by double-sided adhesive tape according to CAST (6DOF) model[17] [Figure 1]. The same investigator attached markers to all the patients.

The patient completed a minimum of 6 walks across the walkway. To minimize the acceleration effect, 0.5 m of their walk before and after initiation and termination was excluded. Data from both walks were combined and represented as a single walking data.

Table 1: Demographics

	Mean±SD
Age	68.45±5.83
Height	1.55±0.08
Weight	71.36±12.12
BMI	29.70±5.24

BMI: Body mass index, SD: Standard deviation

Figure 1: Marker placement by CAST (6DOF) model

Instrumentation

Gait analysis was performed in a 3D instrumented gait lab comprising 9 Qualisys Oqus cameras system (Qualisys AB, Sweden). Data capturing and analysis were done by Qualisys Track Manager (motion capture system). The rate of motion captured was 120 Hz. Kinematic and kinetic data were processed using Visual 3D C-Motion Software, Canada. Midpoints of different events in the gait cycle were recorded in joint kinematics comparison (barefoot) graphs obtained after gait analysis with temporospatial information, GPS, and MAP.

Data collection

Data were collected for parameters as shown in Table 2. The patient-reported outcome measures of TKA were measured using OKS,[18] SF 12 questionnaire,[19] and KSS.[20] The lower score was suggestive of severe OA knee.

Statistical analysis

Statistical analysis was carried out using SPSS Version 20.0 (IBM Corp, Armonk, NY, USA). The Fisher's exact test and Independent *t*-test were used to compare the two groups for categorical variables and continuous variables, respectively, which were deemed significant ($P < 0.05$).

Results

Statistically significant differences were observed between preoperative and postoperative gait for temporospatial parameters (gait speed, Cadence, stance time, step time, step length, stride width, stride length) [Table 3], joint kinematics in the sagittal plane (PSMS, HSMS, HSTS, KSIS, KSMS, ASIS, ASISW), coronal plane (PCISW,

Table 2: 40 kinematic gait parameters

Plane of motion	Pelvis joint	Hip joint	Knee joint	Ankle joint
Sagittal plane	Mid-stance (PSMS)	Initial stance (HSIS) Mid-stance (HSMS) Terminal stance (HSTS) Initial swing (HSISW) Mid swing (HSMSW) Terminal swing (HSTSW)	Initial stance (KSIS) Mid-stance (KSMS) Mid swing (KSMSW)	Initial stance (ASIS) Terminal stance (ASTS) Initial swing (ASISW)
Coronal plane	Initial stance (PCIS) Initial swing (PCISW)	Mid stance (HCIS) Mid swing (HCMSW)	Initial stance (KCIS) Mid-stance (KCMS) Terminal stance (KCTS) Initial swing (KCISW) Mid swing (KCMSW) Terminal swing (KCTSW)	Mid-stance (ACMS)
Transverse plane	Initial stance (PTIS) Initial swing (PTISW)	Initial stance (HTIS) Mid-stance (HTMS) Terminal stance (HTTS) Initial swing (HTISW) Mid swing (HTMSW) Terminal swing (TSW)	Initial stance (KTIS) Mid-stance (KTMS) Terminal stance (KTTS) Initial swing (KTISW) Mid swing (KTMSW) Terminal swing (KTTSW)	Initial stance (ATIS) Mid swing (ATMS)

Table 3: Temporospatial parameters

Parameters	Mean±SD		P
	Preoperative	Postoperative	
Speed (cm/s)	56.68±17.65	71.9±14.7	0.002
Cadence (steps/min)	85.66±22.97	102.94±10.38	0.007
Stance time (% gait cycle)	61.93±5.46	59.35±2.23	0.04
Step time (s)	0.66±0.08	0.59±0.04	0.0001
Step length (m)	0.39±0.07	0.46±0.08	0.0001
Stride width (m)	0.13±0.04	0.10±0.02	0.01
Stride length (m)	0.80±0.18	0.95±0.14	0.01

HCMS, KCIS, KCMS, KCTS, KCISW, KCMSW, KCTSW, ACMS), transverse plane (HTISW, KTTS, KTISW, KTMSW, KTTSW) [Table 4], and MAP (knee flexion/extension, ankle dorsiflexion/plantarflexion, hip adduction/abduction) [Table 5].

A statistically significant difference was observed between preoperative and postoperative OKS, SF 12, and KSS [Table 6]. No significant difference was observed in the remaining gait parameters.

Discussion

Gait analysis is an important tool for the quantification of gait, kinetic, and kinematic of the natural and prosthetic knee. However, it is expensive and has certain limitations such as discomfort due to attachment of markers, unnatural laboratory assessment, and environment. However, it is an important tool for the diagnosis of musculoskeletal disorders,[21,22] surgery outcome evaluation, gait training process, physiotherapy interventions, and effectiveness of different walking aids.[22]

There are data regarding normative temporospatial parameters and joint kinematics in literature from the western population, however, there is a lack of reference for the biomechanics of the replaced knee. Our data focus on the comparative analysis of temporospatial parameters, joint kinematics, GPS, and MAP along with patient satisfaction, general health, and functional score as OKS, SF 12 survey, and KSS. In the following paragraphs, we have discussed different groups of gait parameters.

Temporospatial parameters

Patients are instructed to walk on the walkway at a self-selected speed to gain their most natural walking pattern, as we know, gait pattern is influenced by an increase or decrease in gait speed.[23] The self-selected average gait speed observed in our studied group was 71.9 ± 14.7 cm/s which is lower than previous studies – Hollman *et al*.[24] normative studies (110 cm/s) (mean age – 79 years) and Oh-Park *et al*.[25] (106 cm/s) (mean age – 80 years). Lee *et al*.[26] reported gait speed as 50 ± 14 cm/s in elderly women operated for TKA which was lower than our observed value. Urwin *et al*.[27] reported gait speed as 89 cm/s preoperatively and 101 cm/s after 9 months postoperatively in the fix-bearing TKA group which was higher than our observational values.

The average Cadence observed in our studied group was 102.9 ± 10 steps/min which is lower than studies done by Hollman *et al*.[24] (109 steps/min), Oh-Park *et al*.[25] (105 steps/min), Lee *et al*.[26] which reported Cadence as 82.3 in elderly women operated for TKA, is lower than our observed value. Urwin *et al*.[27] reported a mean Cadence of 101.23 ± 16.8 steps/min postoperatively which was nearly identical to our study observation.

The average stride length observed in our studied group was 0.94 ± 0.14 m which is lower than Hollman *et al*.[24] (male – 1.4 m and female – 1.2) and Oh-Park *et al*.[25] (121 m) observed values. Lee *et al*.[26] reported stride length as 0.73 ± 0.12 in elderly women operated for TKA which was lower than our observed value. Urwin *et al*.[27] reported mean stride length as 1.05 ± 0.15 m preoperatively and 1.11 ± 0.13 meters postoperatively which was higher than our study observation.

Table 4: Significant joint kinematics

Parameters	Mean±SD		*P*
	Preoperative (°)	Postoperative (°)	
PSMS	15.80±6.18	12.62±4.87	0.02
HSMS	17.60±12.91	13.25±8.32	0.05
HSTS	6.52±11.9	1.38±8.68	0.02
KSIS	17.31±9.84	19.26±9.51	0.01
KSMS	15.90±9.73	9.66±8.88	0.0001
ASIS	2.46±4.01	−2.03±4.87	0.0001
ASISW	1.36±5.48	−4.69±8.04	0.0007
PCISW	2.78±4.65	0.39±3.54	0.03
HCMS	−4.16±6.98	3.44±5.36	0.0001
KCIS	5.53±6.87	−2.94±5.61	0.0001
KCMS	6.34±6.56	−2.31±5.52	0.0001
KCTS	3.65±6.53	−5.86±5.46	0.0001
KCISW	0.05±7.16	−8.97±6.70	0.0001
KCMSW	2.82±7.22	−3.85±6.11	0.0003
KCTSW	3.72±6.58	−3.40±5.68	0.0001
ACMS	−3.88±3.84	−1.36±2.61	0.003
HTISW	−12.25±10.12	−4.36±11.02	0.02
KTTS	1.13±10.91	−14.41±11.48	0.0001
KTISW	−1.00±12.24	−16.98±10.71	0.0001
KTMSW	−1.22±11.72	−12.03±13.60	0.01
KTTSW	−3.51±10.06	−15.70±12.43	0.001

SD: Standard deviation

Table 5: Motion analysis profile

Parameters	Mean±SD		*P*
	Preoperative	Postoperative	
Knee flexion/extension	11.73±4.63	9.03±4.38	0.02
Ankle dorsiflexion/ plantarflexion	10.48±2.87	8.10±2.16	0.008
Hip adduction/abduction	9.12±2.94	7.04±2.85	0.02

SD: Standard deviation

Table 6: Knee scores

Parameters	Mean±SD		*P*
	Preoperative	Postoperative	
SF 12 physical score	34.55±5.26	50.69±6.43	0.0001
SF 12 mental score	39.61±6.18	47.52±8.92	0.0001
OKS	12.97±6.51	44.34±4.37	0.0001
KSC-knee score	44.15±4.44	90.52±4.93	0.0001
KSC-functional score	36.06±18.40	86.82±9.75	0.0001

SF12: Short form survey, OKS: Oxford knee score, KSC: Knee society score, SD: Standard deviation

The average step length observed in our studied observed was 0.46 ± 0.08 m which is lower than previous studies by Hollman *et al*.[24] (male – 0.7 m and female – 0.6). Lee *et al*.[26] reported stride length as 0.33 ± 0.06 m in elderly women operated for TKA which was lower than our observed value.

The average step time observed in our studied group was 0.59 ± 0.04 s which is nearly equal to Hollman *et al*.[24] (male – 0.6 s and female – 0.5 s).

Joint kinematics

Compared to a study conducted by Kerrigan et al. on normative young adults (mean age: 28.5 years), our postoperative observations revealed that peak hip flexion (male – 23°, female – 26°) and peak ankle plantar flexion (male 19°, female 22°) were lower for hip flexion (33.44° ±8.49°) and higher for ankle plantar flexion (4.69° ±8.04). The average knee mid-swing in our study group was 55.8° ±7.61° which is also lower compared to study by Kerrigan *et al*.[28] where peak knee flexion was 59° for males and 61.5° for females.

Urwin *et al*.[27] reported maximum knee flexion (54.75° ± 10.6°) and maximum knee adduction (8.39° ± 13.5°) in the preoperative group which was higher than our study observation of 48.8° and 6.34°, respectively. Postoperative maximum knee flexion (64.01° ± 4.02°) and maximum knee abduction (−13.9° ± 12.9°) were higher than our study observation of 55.8° and −8.9°, respectively. No adduction at the knee joint was observed in our study group postoperatively.

The knee sagittal joint angle reported a study by Lee *et al*.[26] in midstance was 6.92° (±2.19°) which was lower than our studied knee sagittal midstance.

A study by Levinger *et al*.[29] reported hip initial contact (36.4°), knee initial contact (14.1°), knee flexion in swing (57.8°), and ankle initial contact (1.3°) in the preoperative group which were higher than our observational study group in hip initial stance (29.85° ± 11.5°) and knee flexion in mid-swing (48.8° ± 17.8°), lower for knee initial stance (17.31° ± 9.84°), and ankle initial stance (2.46° ± 4.1°). Postoperative hip initial contact (36.6°), knee flexion in swing (59.9°), and knee initial contact (12.7°) were higher than our observational study group in hip initial stance (27.97° ± 8.7°) and knee flexion in mid-swing (55.8° ± 7.6°) and lower for knee initial stance (19.26° ± 9.5°).

In our study, the postoperated knee showed lower flexion during the midstance phase and higher flexion angle in the mid-swing phase compared to preoperative sagittal planes joint kinematics. Adduction joint angles observed throughout the gait cycle in the coronal plane preoperatively were changed to abduction throughout the gait cycle postsurgery. Higher postoperative external rotation of the knee throughout the gait cycle was observed when compared with preoperative joint kinematics which is close to normal gait [Figure 2].

Gait profile score and motion analysis profile

MAP parameters correspond to the kinematic variables. In this study, it was observed that there was an improvement (value reduced) in MAP parameters. GPS and walking speed are two separate domains of gait quality. Our study showed no significant change in GPS after TKA but showed significant improvement in the knee (flexion/extension), ankle (dorsiflexion/plantarflexion), and hip (adduction/abduction). No statistically significant change was seen in the remaining MAPs. It suggests that TKA not only improves knee motion but also improves biomechanics of the pelvis, hip, and ankle.

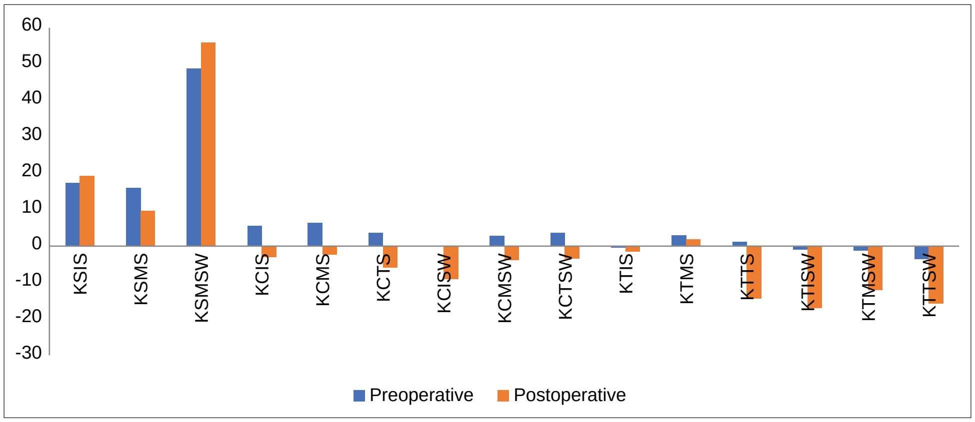

Figure 2: Knee joint kinematics parameters

Functional scores

The statistically better outcomes were observed postoperatively for OKS, SF 12 (mental and physical), and KSS (knee score and functional score). Similar observations were reported for the OKS and KSS by West *et al.*[30] and the OKS and SF 12 by Clement and Burnett.[31]

Conclusion

An objective evaluation and documentation of improvement in pain, function, and gait parameters help the surgeon and therapist to understand the gait pattern and apply their efforts toward the shortcomings with improved portability of the gait analysis. Improvement in perioperative care with focused rehabilitation guided by gait parameters would go a long way and would be the standard of care while treating such patients. The comparison of preoperative and postoperative joint kinematics provides information to implant designers on the design's effectiveness.

Joint kinematics and joint kinetics are important input parameters for TKA. Biomechanical parameters in all three planes are important to identify the actual behavior of the arthroplasty and contribute to a more precise surgery. Our results may be helpful for surgeons and therapists for better functional outcomes and improved postoperative gait patterns.

Author contributions

Conceptualization by Dr. Tanpure, Dr. Phadnis.; methodology by Dr. Nagda, Dr. Rathod.; software, validation, and formal analysis by Dr. Chavan, Dr. Gad.; original draft preparation and writing-review and editing by Dr. Tanpure, Dr. Phadnis, Dr. Rathod. All authors have read and agreed to the published version of the manuscript.

Institutional review board statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of Jupiter Hospital.

Informed consent statement

Informed consent was obtained from all participants involved in the study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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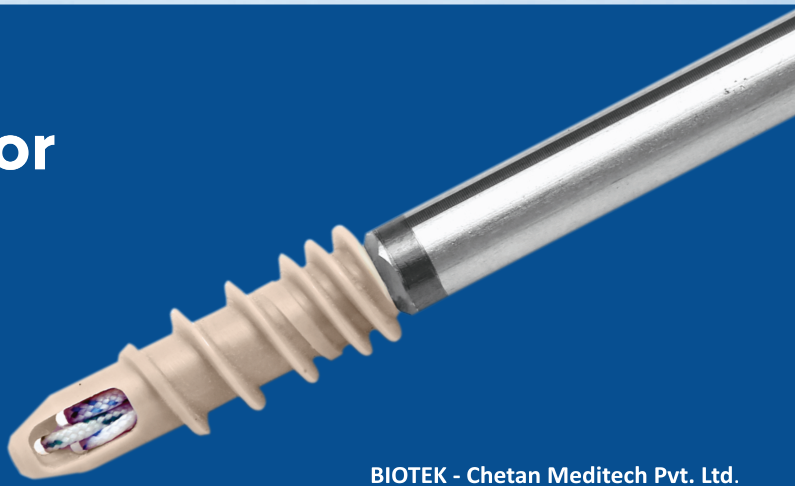

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