

RADIOLOGICAL EVALUATION OF KNEE JOINT DISEASES: THE ROLE OF MODERN DIAGNOSTIC IMAGING TECHNIQUES

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Abstract:

This article provides a comprehensive scientific analysis of the role and significance of modern diagnostic imaging modalities—including ultrasonography (US), conventional radiography, computed tomography (CT), and magnetic resonance imaging (MRI)—in the diagnosis of knee joint disorders. Owing to its anatomically complex structure and substantial functional load, the knee joint is particularly susceptible to a wide range of inflammatory, degenerative, traumatic, and neoplastic conditions. Diagnostic imaging plays a pivotal role in the early detection of these disorders, accurate diagnosis, and the selection of appropriate therapeutic strategies.

The article discusses the physical principles, clinical applications, diagnostic capabilities, advantages, and limitations of each imaging modality based on current scientific evidence. Particular emphasis is placed on the advantages of ultrasonography in the evaluation of soft tissues, the importance of radiography in detecting osseous abnormalities, the high diagnostic accuracy of computed tomography in the assessment of complex fractures, and the role of magnetic resonance imaging as the gold standard for evaluating pathological changes involving the menisci, ligaments, and articular cartilage.

This review serves as a valuable scientific and practical resource for medical students, clinicians, radiologists, and specialists in orthopedics and traumatology.

Keywords: Knee joint; diagnostic imaging; ultrasonography (US); radiography; X-ray imaging; computed tomography (CT); magnetic resonance imaging (MRI); joint disorders; synovitis; joint effusion; gonarthrosis; meniscal tear; ligament injury; neoplastic lesions; bone fracture; three-dimensional reconstruction; soft tissue imaging; skeletal system; joint deformity; inflammatory processes; degenerative diseases; orthopedics; traumatology; diagnostic imaging; joint capsule; Baker's cyst; cartilage injury; osteophyte; osteonecrosis; joint space narrowing; radiological examination.

THE ROLE OF ULTRASONOGRAPHY IN THE DIAGNOSIS OF KNEE JOINT DISORDERS

Ultrasonography (US) is a widely utilized, non-invasive, radiation-free, and safe diagnostic imaging modality that plays a crucial role in the early detection and dynamic follow-up of knee joint disorders. Owing to the anatomical complexity of the knee joint—including the close spatial relationship among soft tissues, ligaments, articular cartilage, muscles, tendons, synovial fluid, and periarticular structures—ultrasonography enables real-time visualization of these anatomical components, making it an invaluable tool in musculoskeletal imaging.

First, ultrasonography demonstrates high diagnostic sensitivity for detecting soft tissue abnormalities, which constitute a substantial proportion of knee joint injuries. Conditions such as patellar tendinopathy, quadriceps tendon injuries, collateral ligament sprains and tears, bursitis, and synovitis can be evaluated with considerable diagnostic accuracy using ultrasonography. Furthermore, the

incorporation of Doppler imaging facilitates the assessment of inflammatory activity by visualizing changes in vascularity and blood flow within and around the joint.

Second, ultrasonography provides valuable information regarding the presence, volume, and characteristics of pathological intra-articular fluid (joint effusion). Excess synovial fluid is commonly associated with synovitis, arthritis, infectious processes, or degenerative joint diseases. In addition to detecting joint effusion, ultrasonography allows evaluation of its mobility, distribution within the joint cavity, and even the presence of fibrin strands or coagulated material, thereby improving diagnostic precision.

Third, beyond its diagnostic capabilities, ultrasonography plays a significant role in guiding minimally invasive therapeutic procedures under real-time imaging control. Ultrasound-guided interventions—including intra-articular injections, arthrocentesis, and regenerative therapies such as platelet-rich plasma (PRP), corticosteroid (hydrocortisone), and hyaluronic acid injections—can be performed with enhanced precision and safety. Consequently, ultrasound guidance reduces the risk of procedural complications while improving treatment efficacy.

Fourth, ultrasonography provides highly accurate evaluation of periarticular mass-like lesions, including Baker's cysts, lipomas, ganglion cysts, and other periarticular abnormalities. In particular, ultrasonography enables precise assessment of the size, wall thickness, internal morphology, and communication of a Baker's cyst with the knee joint cavity, making it an indispensable tool for differential diagnosis.

Fifth, dynamic ultrasonographic examination allows real-time assessment of the functional integrity of ligaments, tendons, and muscles during joint movement. This capability is particularly valuable in athletes and physically active individuals, in whom subtle overuse injuries and microtraumatic lesions frequently occur.

An additional advantage of ultrasonography is its excellent safety profile. The absence of ionizing radiation, relatively low cost, widespread availability, portability, and rapid image acquisition make it an ideal first-line imaging modality in routine clinical practice. Although ultrasonography cannot comprehensively visualize deep intra-articular structures with the same level of detail as magnetic resonance imaging (MRI) or computed tomography (CT), it remains an essential and highly effective technique for the initial evaluation and follow-up of patients with knee joint disorders.

THE ROLE OF RADIOGRAPHY IN THE DIAGNOSIS OF KNEE JOINT DISORDERS

Conventional radiography is one of the oldest, most universally available, and most widely utilized imaging modalities for the diagnosis of knee joint disorders. Its principal advantages include excellent visualization of osseous structures, rapid image acquisition, cost-effectiveness, and widespread availability in virtually all healthcare institutions. Because the knee joint comprises multiple bony components—including the distal femur, proximal tibia, and patella—radiography is considered the first-line imaging modality for the initial assessment of knee pathology.

First, radiography serves as the primary imaging technique for detecting degenerative changes of the knee joint. In particular, the diagnosis of gonarthrosis (knee osteoarthritis) relies on characteristic radiographic findings such as joint space narrowing, osteophyte formation, subchondral sclerosis, subchondral cystic changes, and irregularity of the articular surfaces. Consequently, the internationally recognized **Kellgren–Lawrence grading system** for osteoarthritis is based primarily on radiographic findings.

Second, radiography is regarded as the first-line imaging modality for the evaluation of traumatic knee injuries, including fractures, fissures, dislocations, and subluxations. Even subtle linear fractures (microfractures) may be detected on conventional radiographs. Fractures of the patella, tibial plateau, and femoral condyles are generally well visualized, making radiography indispensable in the initial assessment of acute knee trauma.

Third, radiographic imaging enables accurate evaluation of lower limb alignment and the anatomical relationships between osseous structures. Mechanical axis abnormalities, including varus and valgus deformities (commonly referred to as O-shaped and X-shaped leg deformities), can be quantified through standardized radiographic measurements. Such assessments are essential during preoperative planning for orthopedic procedures, including osteotomy and total knee arthroplasty.

Fourth, radiography provides indirect evidence of several inflammatory joint disorders. In patients with rheumatoid arthritis, radiographic findings may include uniform joint space narrowing, marginal erosions, periarticular osteopenia, and progressive joint deformity. Likewise, crystal-induced arthropathies, particularly gout, may demonstrate characteristic "punched-out" erosions and osseous manifestations associated with tophaceous deposits.

Fifth, radiography also plays an important role in the evaluation of neoplastic bone lesions, including primary bone tumors, metastatic disease, and abnormal osseous proliferation. Although conventional radiography has limited capability in assessing soft tissue abnormalities, it effectively demonstrates cortical destruction, bone infiltration, and other osseous changes associated with tumor involvement. An additional advantage of radiography is the ability to perform functional or stress radiographic examinations. Stress radiographs facilitate assessment of joint stability, collateral ligament integrity, and patellofemoral alignment, thereby providing valuable diagnostic information, particularly in patients with sports-related injuries. Furthermore, compared with other cross-sectional imaging techniques, conventional radiography is associated with a relatively low radiation dose and remains one of the most efficient and cost-effective modalities for the initial screening of knee joint disorders. Despite these advantages, the principal limitation of radiography lies in its inability to adequately visualize soft tissue structures, including the menisci, ligaments, articular cartilage, synovium, and bursae. Consequently, when soft tissue injury is suspected, further evaluation with **magnetic resonance imaging (MRI)** or **ultrasonography (US)** is generally required to establish a comprehensive diagnosis.

APPLICATION OF COMPUTED TOMOGRAPHY (CT) IN THE EVALUATION OF KNEE JOINT PATHOLOGIES

Computed tomography (CT) is a high-resolution diagnostic imaging modality that provides detailed cross-sectional evaluation of knee joint pathologies. CT is primarily employed for assessing subtle morphological abnormalities of osseous and periarticular structures. Owing to the complex anatomy of the knee joint, CT is frequently considered the imaging modality of choice in cases of traumatic injuries, complex fractures, and suspected bone tumors.

First, CT demonstrates excellent diagnostic accuracy in the evaluation of traumatic knee injuries. Fractures involving the femoral condyles, depressed tibial plateau fractures, patellar fractures, and intra-articular fracture extensions are clearly visualized with CT imaging. Furthermore, three-dimensional (3D) reconstruction enables comprehensive assessment of fracture configuration, displacement, angulation, and deformity of bone fragments. These capabilities provide orthopedic

surgeons with valuable information for preoperative planning and selection of the optimal surgical approach.

Second, CT is highly effective in detecting complex intraosseous abnormalities. Lesions such as osteochondritis dissecans, subchondral cysts, areas of bone necrosis, osteolytic lesions, and tumor-like osseous abnormalities can be accurately visualized and precisely delineated. Although CT does not provide soft tissue contrast comparable to magnetic resonance imaging (MRI), it offers exceptional spatial resolution and detailed visualization of cortical and trabecular bone architecture. Third, CT plays an important role in evaluating the geometry and alignment of the articular surfaces. Structural abnormalities commonly encountered in athletes—including patellofemoral dysplasia, trochlear dysplasia characterized by a shallow trochlear groove, patella alta, patellar tilt, and abnormal patellar positioning—can be measured with millimeter-level precision. These measurements are particularly valuable in patients presenting with patellofemoral instability or recurrent lateral patellar subluxation.

Fourth, CT is indispensable for postoperative assessment following orthopedic procedures involving metallic implants, such as osteosynthesis or total knee arthroplasty. Modern CT systems equipped with **metal artifact reduction (MAR)** algorithms substantially minimize image degradation caused by metallic hardware, allowing accurate evaluation of implant positioning, prosthetic loosening, periprosthetic bone integrity, and postoperative complications.

Fifth, CT arthrography—performed following intra-articular administration of contrast material—is an effective imaging technique for evaluating the menisci, articular cartilage, and ligamentous structures. CT arthrography is particularly useful in patients for whom MRI is contraindicated, including individuals with certain cardiac pacemakers, non-MRI-compatible metallic implants, or severe claustrophobia. In such circumstances, CT arthrography serves as a valuable alternative imaging modality.

In addition, CT enables accurate assessment of lower limb alignment, joint deformities, articular surface symmetry, and bone mineral density, facilitating the evaluation of conditions such as osteopenia and osteoporosis. These parameters are of considerable importance in orthopedic surgical planning and postoperative management.

Despite its numerous advantages, CT has several limitations. Because it utilizes ionizing radiation, the associated radiation exposure is higher than that of conventional radiography. Moreover, CT is less sensitive than MRI for evaluating soft tissue structures and may require complementary imaging to fully characterize inflammatory or soft tissue abnormalities. Nevertheless, CT remains an indispensable diagnostic modality, providing comprehensive, high-resolution, cross-sectional evaluation of knee joint pathology and playing a pivotal role in the diagnosis and management of complex osseous disorders.

MAGNETIC RESONANCE IMAGING (MRI): THE GOLD STANDARD FOR THE DIAGNOSIS OF KNEE JOINT DISORDERS

Magnetic resonance imaging (MRI) is distinguished by its superior diagnostic accuracy, excellent soft tissue contrast, and high-resolution multiplanar imaging capabilities in the evaluation of knee joint disorders. Consequently, MRI is widely recognized as the **gold standard** for the diagnosis of numerous knee pathologies. Unlike computed tomography (CT) and conventional radiography, which rely on ionizing radiation, MRI utilizes a strong magnetic field and radiofrequency pulses to generate detailed anatomical images without exposing patients to radiation.

First, MRI is the most accurate imaging modality for evaluating the soft tissue structures of the knee joint. It provides exceptional visualization of the menisci, anterior and posterior cruciate ligaments (ACL and PCL), medial and lateral collateral ligaments (MCL and LCL), articular cartilage, synovial membrane, bursae, and even microscopic inflammatory changes. Owing to its outstanding soft tissue contrast, MRI has demonstrated a diagnostic sensitivity of approximately **93–98%** for detecting sports-related injuries and ligament tears, as reported in the scientific literature.

Second, MRI is superior to both radiography and CT in the evaluation of meniscal pathology. All major types of meniscal tears—including horizontal, radial, vertical, flap, and bucket-handle tears—as well as degenerative changes and meniscal cysts, are clearly demonstrated on MRI. Furthermore, subtle pathological findings such as **meniscal extrusion**, characterized by displacement of the meniscus beyond the tibial articular margin, can be reliably detected only by MRI.

Third, MRI is the most accurate imaging technique for assessing hyaline articular cartilage and enables the detection of early-stage osteoarthritis. While conventional radiography primarily demonstrates joint space narrowing, MRI can identify cartilage thinning, superficial cartilage defects, subchondral bone abnormalities, bone marrow edema, and early inflammatory changes before significant radiographic alterations become apparent. Therefore, MRI possesses the highest diagnostic value for detecting **early-stage (Grade 0–II) osteoarthritis**.

Fourth, MRI is highly effective in the evaluation of inflammatory joint diseases. Rheumatoid arthritis, psoriatic arthritis, synovitis, joint effusion, and intra-articular fibrin deposition can all be clearly visualized on MRI. T2-weighted sequences are particularly valuable for demonstrating synovial fluid accumulation and assessing the extent and severity of inflammatory activity within the joint.

Fifth, MRI is the most sensitive imaging modality for detecting intra-articular hemorrhage, bone marrow edema, occult microfractures, and osteochondral injuries. These subtle pathological changes may not be visible on conventional radiographs and are frequently underestimated or overlooked on CT examinations. MRI is particularly valuable for diagnosing stress fractures and bone contusions ("bone bruises"), which are commonly encountered in athletes and physically active individuals.

Sixth, MRI plays a crucial role in the evaluation of neoplastic lesions involving the knee joint. Soft tissue sarcomas, synovial tumors, synovial chondromatosis, primary bone tumors, and metastatic lesions can be accurately characterized according to their signal intensity, internal architecture, lesion margins, and extent of local invasion. Compared with CT, MRI provides substantially greater diagnostic information for soft tissue tumors. An additional advantage of MRI is the use of gadolinium-based contrast agents, which enhance the visualization of inflammatory lesions, neoplasms, and hypervascular pathological tissues, thereby improving diagnostic accuracy and lesion characterization.

Despite its considerable advantages, MRI has several limitations. Image acquisition requires a relatively long examination time, the procedure is more expensive than conventional imaging techniques, and patients with severe claustrophobia may experience difficulty tolerating the examination. Furthermore, certain metallic implants or non-MRI-compatible medical devices may constitute contraindications or limit image quality. Nevertheless, these limitations do not diminish the outstanding diagnostic performance of MRI. Owing to its unparalleled ability to evaluate soft tissue structures and complex intra-articular abnormalities, MRI is universally regarded as the **gold standard** for the diagnosis of knee joint disorders in contemporary clinical practice.

Conclusion: Diagnostic imaging plays a fundamental role in the evaluation of knee joint disorders and represents one of the most important fields of modern musculoskeletal medicine. The anatomical complexity of the knee joint, its substantial biomechanical load, and the broad spectrum of pathological conditions affecting it necessitate a comprehensive and multimodal imaging approach. Conventional radiography, ultrasonography (US), computed tomography (CT), and magnetic resonance imaging (MRI) are complementary diagnostic modalities, each possessing distinct advantages and limitations that contribute to a comprehensive assessment of knee joint pathology. Conventional radiography remains the most practical and cost-effective first-line screening modality for evaluating osseous structures and degenerative skeletal changes. Ultrasonography provides real-time assessment of soft tissue structures, including ligaments, tendons, the synovial membrane, bursae, and joint effusions, while also serving as an effective tool for image-guided interventions. Computed tomography offers superior visualization of complex fractures, subchondral abnormalities, and osseous components of neoplastic lesions, with three-dimensional reconstruction significantly enhancing preoperative planning. Magnetic resonance imaging, owing to its exceptional visualization of soft tissues, articular cartilage, menisci, and ligamentous structures, is universally recognized as the **gold standard** for the diagnosis of knee joint disorders.

Therefore, accurate and early diagnosis of knee joint diseases requires the integrated application of these imaging modalities according to the patient's clinical presentation and suspected pathology. A contemporary radiological approach emphasizes multidisciplinary collaboration and the appropriate selection of imaging techniques for each clinical scenario. Proper implementation of diagnostic imaging not only facilitates precise diagnosis but also improves treatment planning, enhances clinical outcomes, optimizes patients' quality of life, and contributes to the prevention of long-term complications.

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