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Imaging of Osteoarthritis in Geriatric Patients

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Abstract Imaging of osteoarthritis (OA) in the elderly is gaining importance because of the aging population. It requires knowledge about findings relevant for patient management and others which are abnormal findings, but part of normal aging without relevance for patient management due to lack of clinical symptoms. This review will provide information on what imaging techniques are best used for knee OA and how to systematically assess knee joint structures in order to cover the most common asymptomatic and symptomatic MR findings in OA. We will discuss which findings are typically found in older patients and which are likely to progress to severe pain and disability, finally leading to total joint replacement. The review may aid radiologists and referring clinicians to better understand the evolution of symptomatic OA and the current or future clinical significance of the most common symptomatic and asymptomatic findings.

Keywords Imaging · Osteoarthritis · Geriatrics

Introduction

Osteoarthritis (OA) is the most common joint disease that affects the elderly and results in long-term disability. OA causes loss of articular cartilage, remodeling of subarticular bone, ligamentous laxity, meniscal damage, osteophyte formations, and in some cases effusion and synovitis [1, 2]. These findings occur due to imbalance between the breakdown and repair of joint tissue and some of them may cause symptoms of OA, such as pain, stiffness, and disability. Ultimately disease progression may lead to joint failure.

It is estimated that in the United States of America about 27 million adults suffer from clinically symptomatic osteoarthritis [3]. The knee is the most studied site affected by OA with a lifetime risk from 25 years of approximately 13.83 % overall in the US population, being highest in obese women (23.87 %) [4, 5]. This results in an enormous economical health care cost burden causing billions of dollars spent each year due to treatment [6], which is increasing worldwide due to our increasing prevalence of obesity and aging populations [7–9].

The risk of developing OA is influenced by systemic and local factors. Local factors are, e.g., increased loads on part of the joint caused by muscular dysbalance, leg malalignment, or posttraumatic changes. Several systemic risk factors for osteoarthritis have been identified: obesity, metabolic disease, sex ethnicity, race, genetics, and last but not least, age. Both prevalence and incidence of radiographic and symptomatic knee OA increase with age [1, 2, 10].

Prevalence for knee OA is 1 % in people between the age of 25–34 years and increases up to nearly 50 % in patients 75 years and older. In the Framingham Study, the prevalence of radiographic knee OA was 19.2 % among

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participants older than 45 years of age, whereas at the age of 80 years and older, the prevalence rose up to 43.7 % [1].

Yet, looking at the relationship between age and the risk of OA in more detail, OA appears to develop as the result of many different factors, such as muscle weakening, reduction of proprioception, thinning of cartilage, and inadequate response to joint stress due to break down of basic cellular mechanisms which normally maintain tissue homeostasis in younger patients [1].

Focus of this review will be to summarize symptomatic and asymptomatic findings in OA, particularly as concerns the geriatric population. Radiological findings and new insights in radiographic, morphologic, and compositional MR imaging will be discussed.

Imaging Techniques

Radiographs

Radiography is the most widely used and least expensive imaging modality for OA imaging. The most important features of the bone which are associated with OA are the following: joint space narrowing (JSN), osteophytes, subchondral sclerosis, and cysts [11]. In clinical practice, the semiquantitative Kellgren and Lawrence (KL) grading system [10] is most often used to define radiographic OA and grades the presence of osteophytes, whereas joint space width (JSW) is a surrogate of cartilage thickness and meniscal integrity. Progression of JSN is commonly used to assess progression of structural OA, and total loss of JSW is a relevant indicator for joint replacement [12]. In a longitudinal study over 8 years, 0.1 mm of narrowing of JSW over 3 years was associated with an increased risk of knee replacement of 14 % [13]. Therefore, JSW has clinical relevance regarding the progression of the disease and was recommended as focus in the quantitative assessment of OA progression [14].

However, radiography is of limited use especially in early OA, due to its insensitivity for soft tissue joint structures involved in the pathogenesis of OA. Also, the inter-observer reliability for the progression of radiographically detected features associated with OA is low [15].

MRI

Compared to radiography, MRI is superior in providing information on the following soft tissue joint structures: articular cartilage, menisci, ligaments, synovium, joint effusion, bone marrow lesions (BMLs), and capsular structures [16–24]. Therefore, an MRI-based definition of OA has been proposed recently [25]. In a previous study

with 1766 subjects from the population-based Rotterdam study, MRI-based and radiographic OA definitions were compared, resulting in a higher detection rate of OA in MRI compared to radiographs (7 vs. 4 %) [26]. In the same study, higher associations between clinical symptoms and joint abnormalities were found using MRI for definition of OA. The OA Research Society International (OARSI) recommends MRI as suitable for cartilage imaging in clinical trials [27]. Imaging with 3.0-T scanners provides substantial gain in signal and spatial resolution compared with 1.5-T scanners. Improvements in the quality of images acquired with 7.0-T scanners are currently being explored; imaging at 7.0 T may have use for the research applications but will not be applied clinically.

For morphological MR imaging, intermediate-weighted (IW) 2D fast spin-echo (FSE) sequences have been shown to be most useful for clinical imaging as well as for clinical trials, but 3D fast spin-echo (FSE) sequences, 3D dual-echo in steady state (DESS) sequences with selective water excitation (WE), and 3D T1-weighted fast low-angle shot (FLASH) sequences have also been used. Additionally, studies have reported benefits from contrast-enhanced sequences regarding the evaluation of synovitis [Multi-center Osteoarthritis Study (MOST)] [28].

Morphological MRI

Structural abnormalities of the knee joint can be assessed both cross-sectionally and longitudinally with semiquantitative MRI assessment scores, such as the Whole-Organ Magnetic Resonance Imaging Score (WORMS), which is considered to be a reliable, specific and sensitive score for the analysis of knee joint structures [29]. The use of within-grade changes for longitudinal assessment of, e.g., cartilage damage has been applied in order to increase sensitivity to change. Alternatively, semiquantitative analysis scores such as Knee Osteoarthritis Scoring System (KOSS) [30], the Boston Leeds Osteoarthritis Knee Score (BLOKS) [31], and the MRI Osteoarthritis Knee Score (MOAKS) [32] have demonstrated valid within-grade changes and their use increases the sensitivity in detecting longitudinal structural changes [27, 33]. Quantitative Scores such as the Cartilage Lesion (CaLS) score have been developed specifically for the assessment of cartilage lesions using three-dimensional measurements, once morphological lesions are detectable [34]. Nevertheless, the mentioned semiquantitative and quantitative scoring systems are limited to the assessment of the amount of structural changes and their progression, but they are insensitive for biochemical and compositional changes in the cartilage before morphological lesions occur. For the detection of these very early and potentially reversible changes, compositional MRI techniques have been developed.

Compositional MRI

Compositional MRI enables the visualization of the biochemical composition of joint tissue. Therefore, this technique can detect changes in composition before morphological abnormalities appear. Studies on compositional MRI mainly focus on cartilage imaging, although it has been proven to be useful for the assessment of other joint structure, such as the menisci, previously [35]. The three most used MRI techniques consist of delayed Gadolinium Enhanced Magnetic Resonance Imaging of Cartilage (dGEMRIC), T1 rho, and T2 mapping [36–40].

Several longitudinal studies have demonstrated that dGEMRIC allowed to predict structural changes in the knee joint. Previously, in patients that underwent meniscal surgery, high JSN and more osteophytes medially, as measured on radiographs 11 years after surgery, were associated with low dGEMRIC indices, assessed 1–5 years after surgery [41].

Still, dGEMRIC requires IV gadolinium application followed by exercise, which may not be suitable for all patients. A noninvasive alternative used for the majority of compositional imaging knee studies is T2 relaxation time mapping. It has been shown to predict the onset of radiographic OA over 48 months, with elevated T2 values in subjects that developed OA compared to controls without OA [42]. Also, T2 texture parameters, as a measure of the cartilage extracellular matrix structure in three dimensions, have demonstrated higher and more heterogeneous cartilage T2 values in subjects at risk for OA compared to controls [43]. However, compositional imaging has limitations, especially in later stages of OA. Once morphological changes of cartilage occur, validity may be limited regarding the evaluation of further cartilage degeneration [44]. Therefore, ideally, the combination of compositional and morphological MR imaging should be used in order to monitor cartilage status longitudinally.

Imaging Findings and Their Clinical Significance

Cartilage Defects

OA is characterized by the progressive loss of hyaline articular cartilage, which can be evaluated with magnetic resonance imaging (MRI) [45, 46]. Baum et al. found a relation between cartilage defects and knee pain, when comparing subjects without knee pain to subjects with either right knee or bilateral knee pain [47•]. Previously, an inverse association between diffuse cartilage degeneration, assessed with cartilage volume measurements, and pain, assessed with the WOMAC subscale for pain, has been demonstrated in multiple studies [48, 49]. In contrast, focal

cartilage lesions, including cartilage signal abnormalities without a partial- or full-thickness cartilage defect, showed no significant association with knee pain [47•]. This may be due to the fact that cartilage defects alone do not immediately generate pain, since it does not contain nociceptors [50]. However, cartilage defects may cause altered biomechanical loading and therefore greater deforming stress on the underlying subchondral bone (Fig. 1) [50, 51], which, in contrast to aneural cartilage, can perceive nociceptive stimuli. A further underlying pathomechanism for the association between cartilage defects and knee pain may also be a higher level of disease activity leading to inflammatory processes with increased levels of chondrolytic enzymes [52]. Nevertheless, the exact underlying causality of cartilage defects and knee pain remain unclear. In summary, these findings suggest that cartilage defects are highly associated with knee pain and symptoms.

Compositional Imaging: Cartilage T2 Relaxation Time Mapping

Since OA is characterized by loss of hyaline articular cartilage, which is the result of previously damaged collagen-proteoglycan matrix and increased water content of the cartilage [53, 54], MR imaging enables the noninvasive detection of changes and differences in biochemical composition of cartilage at early stages of OA [43, 55]. In a study investigating the characteristics of cartilage T2 values longitudinally in asymptomatic individuals without risk factors for OA, T2 values appeared to be age-dependent, demonstrating an age-related increase in cartilage T2 over 24 months [56]. This finding was consistent with previous studies, in which cartilage T2 increase progressed from the superficial layer to the deep layer in a laminar analysis [57–

Fig. 1 Meniscal tear, cartilage defects, and bone marrow lesions: **a** A 63-year-old male patient with a degenerative, oblique meniscal tear, without knee pain (WOMAC pain sub-score of 0)—fat-suppressed intermediate-weighted MRIs showing a hyperintense oblique meniscal tear of the posterior horn of the lateral meniscus (white oblique arrows). **b** 70-year-old female patient with severe knee pain (WOMAC pain sub-score of 14) with severe cartilage loss at the patella, trochlea, and lateral femur (white dashed arrows) as well as bone marrow edema pattern (white vertical arrows) combined with small subchondral cysts (white horizontal arrows)

59]. Also, in this study, increase in cartilage T2 correlated with progression of cartilage abnormalities.

In an analysis adjusted for age, T2 values were found to be elevated in subjects with knee pain, compared to subjects without knee pain (Fig. 2) [47•], in a cohort without radiographic evidence and with risk factors for OA, suggesting deterioration of cartilage quality is associated with findings of pain in the early phase of OA. This finding is of particular interest, since subjects with knee pain and at early stage of cartilage deterioration may benefit from treatment and lifestyle interventions most and monitoring of cartilage matrix integrity with longitudinal T2 measurements might enable identification of individuals at risk for development of OA before irreversible cartilage loss occurs [56].

Osteophytes

Osteophytes may be related stronger to pain severity than other radiographic features, such as joint space width (Fig. 3), as demonstrated previously [60]. A further study found an association between the number of osteophytes and pain if there were more than four osteophytes detected in the entire knee [61]. Although there was no association found between central osteophytes and pain in this study, as previously described, in summary these studies suggest that there is an association of osteophytes with pain. It has been discussed that this association is partially caused by simultaneous bone attrition and/or bone marrow lesions, which can barely be detected by radiographs. Therefore, current studies focus more on MR imaging findings in the subchondral bone, such as subchondral cysts and bone marrow edema, which can be summarized as bone marrow lesions (BMLs).

Bone Marrow Lesions

Several previous studies have reported associations of knee pain with bone marrow edema pattern [60, 62–64], whereas others have shown no association [65–67]. In order to

Fig. 2 Compositional T2 relaxation time imaging: **a** 55-year-old female patient without knee pain (WOMAC pain subscale of 0) with normal cartilage T2 relaxation times in the medial tibia of the right knee; **b** showing increased cartilage T2 relaxation times in a 70-year-old male patient with severe knee pain (WOMAC pain subscale of 15) in the medial tibia. T2 maps were acquired using 3T MR imaging

investigate this association, Felson et al. evaluated the incidence and progression of BMLs in over 15 months in 330 subjects at high risk for or with knee OA and with and without knee pain [64]. This study found strong evidence for BMLs being partially responsible for pain, especially the progression of preexisting BMLs, yet given the fairly high percentage of controls without knee pain and with BML enlargement (26.8 vs. 49.1 %), the authors conclude that it is likely that BMLs might not be the single source of pain development. Due to this ambiguous data, further research is required, possibly including analysis of bone attrition, given that one prior study suggested that bone attrition is required for bone marrow edema pattern to contribute to pain severity [68], after Dieppe et al. had found evidence for a possible link between radiographic bone attrition and night pain [69]. In summary, these findings suggest that BMLs are highly associated with knee pain and symptoms. Moreover, inflammation within the joint or effusion enlargement has been considered as a possible factor causing knee pain [62, 63, 70•].

Joint Effusion and Synovitis

A substantial amount of effusion causes a distention of the capsule, therefore it is plausible that effusion has been associated with pain in multiple studies [60, 61, 71]. A cross-sectional study by Lo et al. found effusion and synovitis, assessed with Boston Leeds Osteoarthritis Knee Score (BLOKS) in 160 patients with radiographic evidence of knee OA and symptoms, to be associated with weight-bearing and non-weight-bearing knee pain (Fig. 4) [63]. However, a limitation of this study was the fact that synovitis was assessed with non-contrast-enhanced (non-CE) images.

Fig. 3 Osteophytes and joint space narrowing: **a** Anteroposterior left knee radiograph of a 65-year-old female patient with mild knee pain (WOMAC pain sub-score of 5) and a lateral and medial tibiofemoral osteophytes (white oblique and horizontal arrows), as well as mild medial tibiofemoral joint space narrowing (white vertical arrows). (B) Tibial and femoral osteophytes confirmed in the same patient on coronal proton-density-weighted MR image (white dashed arrows)

Fig. 4 Effusion and synovial thickening: Sagittally acquired fat-saturated 3D CUBE sequences (TR, 1500; TE, 27; slice thickness, 1 mm) of the right knee of patients with severe knee pain and effusion and synovial thickening—**a** showing an effusion of 4 mm as measured in the lateral compartment just mesial to the fibular head, using the suprapatellar recess as point of reference (between the arrows) and a thickening of the synovial membrane of 2–3 mm (dashed arrows). **b** showing an effusion of 7 mm (between the white arrows) and a minor thickening of the synovial membrane of 1 mm (dashed arrow). These findings are typically associated with clinical symptoms

Estimating the extent of synovitis in non-contrast-enhanced sequences is difficult. Since synovitis is an important feature in OA [60, 62, 72], as it is innervated tissue [73–76] and inflammation of the synovium may cause pain, there was need for a more accurate visualization and assessment of the relation between synovitis and pain. Therefore, Baker et al. obtained CE MRIs in the Multicenter Osteoarthritis Study (MOST) in 454 individuals. In this study, synovitis was detected in 80 % of the subjects with knee pain [70]. In summary, these studies suggest that joint effusion and synovitis are highly associated with knee pain.

All these studies mentioned so far support the current opinions on OA being multifactorial in etiology and that pain may result from different processes, which in parts are independent and in parts depend from one another. In general, whole joint kinematics suggest that the disruption to knee joint mechanics may be associated with the development of symptoms. However, as mentioned, in previous studies certain degenerative changes in OA have shown no significant associations with knee pain [47].

Meniscal Damage

Another feature, which may often be the first signal for osteoarthritic disease, is degenerative meniscal damage appearing as a meniscal tear [77].

In a study, performed by Englund and co-workers, meniscal finding in knees of 991 individuals ranging from 50 to 90 years of age was analyzed [78]. In this study, the prevalence of meniscal damage increased with increasing age in both sexes, from 19 % in 50–59-year-old subjects to 56 % in 70–90-year-old subjects. The meniscal tears were more frequently found in subjects without clinical symptoms. This finding is corroborating previous studies demonstrating that most meniscus abnormalities are not associated with pain [60, 61].

Baum and co-workers compared subjects without knee pain to subjects with knee pain and not only found no association between meniscal lesions and pain, but also no association between meniscal tears and cartilage T2 values, suggesting no impairment of integrity in cartilage neighboring the damaged meniscus [47]. This is consistent with previous studies reporting that the surgical removal of damaged parts of the meniscus lacks evidence of reducing pain substantially [79, 80]. Because only the outer part of the menisci is innervated, it is plausible that lower grade tears, such as minor radial tears, which occur most frequently in subjects with OA, do not lead to knee pain. In summary, currently, degenerative meniscal damage is considered as a mostly asymptomatic finding in OA that frequently occurs in the elderly without contributing to clinical symptoms and, therefore, may be part of normal aging.

Ligamentous Lesions

In a study performed by Baum and co-workers, chronic ligamentous lesions were not associated with pain, as reported previously [47, 61]. Although Torres and co-workers had found a high odds ratio between chronic LCL changes and pain, they justified these results with an extremely wide 95 % confidence intervals, which very likely reflected the small number of knees with LCL changes (LCL grade 2 = 1 %; LCL grade 1 = 4 %) and was not due to an eventual association [60]. Another study analyzed 358 randomly selected subjects for ligament damage, regardless of knee OA or pain. Incidental cruciate findings on MRI were common in this elderly population and had a higher prevalence of a history of knee injury in those with cruciate ligament tears compared to those without. Moreover, cruciate ligament tears were observed in 37.5 % of the subjects with knee OA compared to only 7.5 % of the non-OA subjects. Cruciate tears did not significantly correlate with knee pain after adjusting for cofounders [81]. A further study showed that individuals with complete ACL tear did not have more knee pain compared to individuals with intact ACL [82]. Therefore, ligament tears may be associated with specific patterns of knee degeneration, yet, ligament damage alone does not seem to directly induce knee pain.

Conclusions

OA is the most common joint disease that affects the elderly and age is one of the most important risk factors for this disease. Yet, it is critical to distinguish between abnormal findings, which are part of normal aging and, therefore, have no pathophysiological consequences regarding symptoms and treatment. Studies suggest that certain radiological findings, such as meniscal damage, are part of normal aging, whereas cartilage defects, bone marrow lesions and synovitis were associated with knee pain and worsening of clinical status. Therefore, the detection and quantification of regional knee joint abnormalities must be seen in context with the demographic and clinical parameters to ensure the adequate evaluation of the individual knee joint status, which may determine further therapeutic decisions.

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Compliance with Ethics Guidelines

Conflict of Interest Alexandra S. Gersing reports grants from NIH. Thomas M. Link reports grants from NIH and is the Editor-in-Chief of *Current Radiology Reports*.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by the authors.

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