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Review

Imaging following acute knee trauma

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SUMMARY

Joint injury has been recognized as a potent risk factor for the onset of osteoarthritis. The vast majority of studies using imaging technology for longitudinal assessment of patients following joint injury have focused on the injured knee joint, specifically in patients with anterior cruciate ligament injury and meniscus tears where a high risk for rapid onset of post-traumatic osteoarthritis is well known. Although there are many imaging modalities under constant development, magnetic resonance (MR) imaging is the most important instrument for longitudinal monitoring after joint injury. MR imaging is sensitive for detecting early cartilage degeneration and can evaluate other joint structures including the menisci, bone marrow, tendons, and ligaments which can be sources of pain following acute injury. In this review, focusing on imaging following acute knee trauma, several studies were identified with promising short-term results of osseous and soft tissue changes after joint injury. However, studies connecting these promising short-term results to the development of osteoarthritis were limited which is likely due to the long follow-up periods needed to document the radiographic and clinical onset of the disease. Thus, it is recommended that additional high quality longitudinal studies with extended follow-up periods be performed to further investigate the long-term consequences of the early osseous and soft tissue changes identified on MR imaging after acute knee trauma.

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Introduction

Joint injury is a well-known and potent risk factor for osteoarthritis[1]. The driving mechanisms of the increased risk remain unknown, but various factors are thought to influence the likelihood of developing post-traumatic osteoarthritis including the severity of injury, the joint tissues involved, the age at the time of injury, and the time from the onset of injury[2]. Investigating the pathogenesis of post-traumatic osteoarthritis in human subjects is challenging and requires non-invasive methods to monitor joint injury. Radiography is the imaging modality primarily used to detect the onset and progression of joint degeneration following trauma, but the development of radiographic features of osteoarthritis may take decades to occur[3–7].

Advanced imaging techniques including magnetic resonance (MR) imaging have recently been used for longitudinal assessment of patients following acute trauma and show great promise for detecting early manifestations of joint degeneration. The vast majority of longitudinal studies using imaging technology have focused on the injured knee joint, specifically in patients with anterior cruciate ligament (ACL) injury and meniscus tears where a high risk for rapid onset of post-traumatic osteoarthritis is well known[8–10]. Few longitudinal studies have used advanced imaging technology to investigate the progression of joint degeneration from its earliest stages after acute injury to the onset of radiographic and clinical manifestations of osteoarthritis.

This article will review the imaging modalities currently available for longitudinal joint assessment in patients with acute knee trauma and will discuss the current knowledge on imaging based structural injury and longitudinal changes in joint structures after knee trauma. The article will also review the current evidence on the association between imaging based structural injury following knee trauma and clinical outcome, molecular changes in joint tissue, and the onset of osteoarthritis. The review is based on an extensive PubMed literature search which included but was not

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limited to the following search terms: ACL, trauma, sports injury, knee, imaging, radiography, computed tomography (CT), MR imaging, osteoarthritis, treatment, and outcome. While every attempt has been made to incorporate all relevant literature into the review, it must be acknowledged that this manuscript is a narrative review and not a systematic review according to PRISMA guidelines.

Panorama of structural injury following acute knee trauma

Acute rotational trauma combined with a rapid effusion of the knee joint is highly suggestive of a significant intra-articular injury[11,12]. Clinical examination of the injured knee is often difficult in the acute setting, and a lack of accuracy for detecting intra-articular pathology has been well documented[13,14]. A study from 2007 highlights the benefit of using MR imaging to determine the extent of structural damage following knee trauma by showing that only 12% of transient patellar dislocations and 50% of ACL tears identified on MR imaging were clinically suspected in the orthopedic emergency room[14]. The overall panorama of structural injury after acute knee trauma is not well known. A recent abstract from a large study on 1145 patients with acute knee trauma, who were evaluated with MR imaging within a median of 8 days after injury, showed an ACL tear, transient patellar dislocation, and medial collateral ligament tear in 52%, 17%, and 28% of individuals respectively[15]. The majority of patients, except those with transient patellar dislocations, suffered from a combination of structural injuries. A concomitant meniscus tear was identified in 55% of patients with ACL injury, while an isolated ACL tear was found in only 17% of individuals[15]. Osseous injuries including traumatic bone marrow lesions[16–22] and cortical fractures[23,24] were also identified in a large proportion of patients with ACL tear. The combination of structural injuries sustained during acute knee trauma may potentially influence long-term clinical outcome and the development of osteoarthritis.

Imaging methods for longitudinal assessment of patients following acute knee trauma

Radiography

Radiography is commonly used to evaluate patients following acute knee trauma. Various radiographic grading scales including the Osteoarthritis Research Society International (OARSI) atlas[25], Kellgren–Lawrence[26], Ahlback[27], and Brandt[28] systems are currently available to assess the degree of joint degeneration based upon the presence of osteophytes, subchondral cysts and sclerosis, and joint space narrowing. As the OARSI atlas grading scheme incorporates a compartmental assessment of osteoarthritis features and scores joint space narrowing and osteophyte presence as separate items, it seems best suited for the assessment of post-traumatic osteoarthritis when compared to composite scales like the Kellgren–Lawrence system. However, for knee phenotypic characterization and patient inclusion in longitudinal studies, the Kellgren–Lawrence scale is still commonly applied and has been found to be a helpful instrument.

Quantitative measurement of joint space width on standing flexion anterior–posterior knee radiographs, acquired using standardized positioning and imaging protocols, has also been shown to have high precision and is thus well suited as a longitudinal assessment measure of cartilage degeneration[29–32]. Quantitative assessment of knee radiographs has been found to be comparable to MR imaging for detecting osteoarthritis progression and is possibly superior when considering cost-effectiveness[33]. However, fixed-location radiographic measures are incapable of determining the spatial distribution of tibiofemoral cartilage loss[34]. Furthermore, it should be noted that joint space narrowing on knee radiographs can be due to factors other than cartilage loss[35,36] and that radiographs have poor sensitivity for detecting early cartilage degeneration[37] and progressive cartilage loss over time[38]. Therefore, long follow-up periods are needed to document the onset and progression of joint degeneration in patients with knee injury using radiography. Despite its limitations, radiography was the first imaging method to document the high incidence of osteoarthritis in patients with ACL injury and meniscus tears (Fig. 1)[3–7].

CT arthrography

CT arthrography with intra-articular contrast has been used to evaluate patients following acute knee trauma and has been shown to have high sensitivity for detecting various features of joint degeneration including meniscus and ligament tears, cartilage loss, subchondral cysts and sclerosis, and osteophytes[39–42]. The technique can also be used to assess the thickness[43,44] and proteoglycan concentration[45,46] of articular cartilage which may provide quantitative measures for longitudinal joint assessment. However, CT arthrography is an invasive procedure and involves radiation expose which limits its use in longitudinal studies. CT arthrography can be useful for detecting fractures following acute knee trauma and as an alternative imaging modality for longitudinal joint assessment in patients with contraindications to MR imaging.

Morphological MR imaging

Due to its ability to detect early morphologic degeneration in joint structures, MR imaging is a powerful tool for longitudinal assessment of patients following acute knee trauma[47,48]. MR imaging is sensitive for detecting early cartilage degeneration when using high field strength scanners and advanced imaging protocols[49] and can evaluate other joint structures including the menisci, bone marrow, tendons, and ligaments which can be sources of pain following acute injury[50]. Several semi-quantitative MR-based scoring systems are currently available for longitudinal evaluation of knee osteoarthritis in research studies[51–53]. However, these instruments are only partially applicable in patients with ACL injury as they do not include a detailed description of the baseline injury patterns which may influence clinical outcome. Furthermore, subchondral bone marrow changes due to trauma need to be differentiated from degenerative bone marrow lesions, which are not covered by commonly used osteoarthritis scoring tools, and ligament graft signs of inflammation and laxity need to be considered[54–56].

An MR-based instrument incorporating acute traumatic and subsequent degenerative alterations was recently introduced, the Anterior Cruciate Ligament OsteoArthritis Score (ACLOAS)[57]. ACLOAS evaluates baseline structural joint damage such as osseous injuries and meniscus tears and also assesses features of osteoarthritis including degenerative bone marrow lesions, osteophytes, and cartilage loss (Fig. 2). In addition, signs of inflammation and laxity of the ligament graft are evaluated. ACLOAS was developed and tested using data from the Knee Anterior cruciate ligament NON-operative versus operative treatment (KANON) trial KANON trial[58,59], and its applicability was shown for cross-sectional and longitudinal scoring with good to excellent reliability for most features[57]. However, its validity in regard to clinical outcomes needs to be further investigated in longitudinal follow-up studies.

MR imaging morphometry

Morphometry is a quantitative MR analysis method used to derive three-dimensional measures of tissues and can be applied to cartilage, meniscus, bone, or muscle. Typically, measures of

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