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Research article

T2 relaxation times of the anterolateral femoral cartilage in patients after ACL-reconstruction with and without a deep lateral femoral notch sign

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ABSTRACT

Purpose: To quantitatively assess T2 relaxation times of the anterolateral femoral cartilage following anterior cruciate ligament (ACL)-reconstruction with and without a positive deep lateral femoral notch sign (DLNS) at post-traumatic MRI.

Materials and Methods: In 52 patients post-traumatic MRI as well as 12 months after ACL-rupture (ACLR) and surgical treatment were analysed. In 28 patients a positive DLNS was present at post-traumatic MRI.

For quantitative analysis, T2 relaxation time measurements (7 TE: 10–70 ms) were performed at time of re-evaluation. Three polygonal ROIs encompassing the full cartilage layer were placed in the anterolateral femoral cartilage. Clinical assessment included Lysholm-Tegner-Activity-Score, Rasmussen's clinical score and modified Cincinnati-Rating-System-Questionnaire. Description and differences were calculated as means and confidence intervals of means, controlled for the cluster effect of person, if appropriate.

Results: In patients with a positive DLNS after ACLR, relaxation times in the notch region were significantly prolonged compared to patients without a positive DLNS (Δ 7.4 ms, CI: 5.6–9.2; p-value < 0.001) as well as to the adjacent anterior (Δ 5.7 ms, CI: 4.7–6.7; p-value < 0.001) and central femoral cartilage (Δ 6.6 ms, CI: 5.7–7.6; p-value < 0.001).

Solely insignificant differences were noticed in the performed clinical scores comparing the two groups (p > 0.05).

Conclusion: Significantly prolonged T2 relaxation times of the anterolateral femoral cartilage were found in patients with a positive DLNS following ACL-reconstruction compared to patients without a DLNS. Based on these results, it has to be assumed that a positive DLNS is associated with higher cartilage degradation.

1. Introduction

Acute rupture of the anterior cruciate ligament (ACL) is one of the most feared injuries in sports overall.

Considering the high incidence of Anterior-Cruciate-Ligament-Ruptures (ACLRs) of more than 200.000 injuries in the US alone [1,2], the immense relevance becomes evident. The impact on every athlete's career is underlined by reviewing the therapeutic consequences after ACLRs. Usually, post-traumatic surgery and at least six months of rehabilitation are mandatory in order to return to regular athletic activity [3].

However, it is reported that only 48% of elite Australian football players could return-to-play in less than one year [4]. Furthermore, studies could demonstrate that in the majority of patients after an ACLR signs of osteoarthritis (OA) are detectable within 10–15 years [5,6].

In post-traumatic diagnostic evaluation of ACLR, concomitant injuries are presumably to be diagnosed. In approximately half of all patients suffering from ACLR, an articular cartilage injury is noted [7]. In an extensive trauma mechanism, due to a dorsolateral movement of the femur and a fixed lower leg ("pivot shift manoeuvre"), a

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transchondral impression of the anterolateral femoral condyle versus the dorsolateral tibial plateau can result.

This constellation can be detected at post-traumatic radiography (lateral view), known as the deep lateral notch (sulcus) sign (DLNS) [8].

It has been reported that in high-pivoting sports in about 33% of patients after acute ACLR, a positive DLNS deeper than 2 mm can be observed [9].

At MRI a DLNS is accompanied by subchondral bone marrow edema in the distal femur in about 50% of patients [9].

In the recent decade various techniques have drawn attention to quantitative MRI measurements of articular cartilage. Techniques such as T1rho or T2/T2* have demonstrated that early stages of OA might be diagnosed prior to irreversible stages [10–13]. T2 mapping is based on the detection of increased water observed in cartilage degradation due to biochemical changes in the extracellular matrix (e.g. collagen fraction).

High sensitivity rates for the indirect assessment of early stages of OA for T2 mapping have been published in various studies [10,28].

In our investigation of post-operative femorotibial joints in patients after ACLR, we decided to include T2 mapping as the most validated technique for quantitative measurements. T2 mapping has been used in many clinical trials for it offers several advantages (e.g. no i.v. contrast media required, robust against susceptibility artifacts) while being highly sensitive to biochemical changes in articular cartilage composition [10,14,15].

Progressive cartilage degradation has been generally confirmed in recent publications after ACLR up to two years after surgery compared to healthy individuals [16–18].

However, to the best of our knowledge, no dedicated quantitative analysis of the DLNS has been performed yet. Therefore, the purpose of the presented study was to analyse and compare T2 relaxation times in patients suffering from ACLR with and without a DLNS.

We intended to evaluate if the DLNS is accompanied with altered relaxation times indicating a more severe traumatic event and higher cartilage degradation. Therefore, all patients were re-evaluated including quantitative T2 measurements as well as several clinical knee-scores 12 months post-trauma.

2. Materials & methods

Approval from the local institutional review board was received prior to initiation of the study. Informed patient consent was obtained from all patients before image acquisition.

2.1. Study population and Inclusion/Exclusion criteria

All patients in our database, who were diagnosed with ACLR (between 2014–2015) prior to the study were contacted and asked to voluntarily participate in our study. In total, 59 out of 124 patients took part in our investigation (47%). Four patients refused an MRI examination at re-evaluation and were consequently excluded. Three patients were excluded because their knees did not fit inside the 16-channel knee coil. Therefore, the quantitative imaging protocol was not applicable. Therefore, 52 patients (18 female, 34 male; mean age at re-evaluation: 32.5 years) were enrolled.

Exclusion criteria were: 1.) Surgery prior to ACLR on the injured knee, 2.) Acute injury or history of major injury after ACLR (e.g. fracture) or 3.) Systemic diseases like e.g. rheumatoid arthritis.

All scans at time of re-evaluation were conducted between August 2015 and April 2016.

2.1.1. Image acquisition

All patients underwent morphological and quantitative MRI imaging protocol at re-evaluation. Morphological sequences were acquired prior to T2 relaxation measurements. The order was kept constant in all patients. At both time points, all MRIs were performed using a 3 T MRI system (Ingenia, Philips, Best, the Netherlands). A 16-channel knee coil was used for signal reception. The investigated knee was placed in the centre of the coil and sandbags positioned on patient's leg.

2.1.2. Morphological sequences

Sagittally oriented 3D fat-saturated proton-density weighted (Pdw) Turbo Spin Echo (TSE) sequence was performed and reformations subsequently generated. The parameters were kept identical at both time points: Time to repetition (TR) 1300 ms; echo-time (TE) 3.7 ms; flip angle: 90°, slice thickness: 0.6 mm (in total: 330 slices), field of view (FoV): 185 × 185 mm, matrix: 320 × 320, scan time: 8:24 min. In addition, a coronal T1w TSE sequence was acquired (TR: 818 ms, TE: 10.8 ms, flip angle: 90°, slice thickness: 2.2 mm (in total: 60 slices), matrix: 672 × 672, FoV: 180 × 180 mm, scan time 1:50 min. For quantitative measurements, a 3D multi-echo T2w Turbo Spin Echo (TSE) sequence was used (TR: 192.8 ms, 7 echo times (10–70 ms), flip angle: 90°, slice thickness: 3 mm, matrix: 320 × 320, FoV of 160 × 160 mm, Sense factor: 4.4, scan time: 6:15 min). T2 mapping was performed by fitting a monoexponential function A*exp(–TE/T2) to the multiecho data using an in-house quantification plugin (qMapIt) extending ImageJ (National Institutes of Health, Bethesda, MD). The first echo was neglected because it does not contain any signal of a stimulated echo in contrast to the later ones.

2.1.3. Morphological image analysis

All patients underwent biplane radiography (anterior-posterior and lateral view) of the injured knee in the emergency department at the day of trauma. These were evaluated in accordance to the Kellgren-Lawrence grading for signs of OA [19].

All MRIs between 2014 and 2015 were scanned for ACLRs by two radiologists with special interest in sports imaging (five and 12 years of experience).

If both radiologists diagnosed ACLR, MRIs were re-evaluated for additional injuries. If the readers had divergent opinion concerning the status of the ACL or concomitant injuries, they reviewed the anonymized data sets and formed a consensual diagnosis [2,20,21].

Morphological analysis was performed by using a commercially available post processing workstation (Extended Brilliance Workspace, Version 2.0, Philips Healthcare, Best, the Netherlands). Concomitant injuries were noted as listed below:

a) impression of the anterolateral femoral condyle, b) bone marrow edema, c) rupture of the collateral ligaments, d) cartilage lesions according to Noyes classification higher than grade 2 [22], e) rupture of the retinaculum patellae, f) injury of the Hoffa fat pad, g) fracture, h) meniscal injuries (lesions of the anterior or posterior horn as well as bucket handle tears, i) rupture of the patellar tendon.

In patients with a DLNS sign, maximum length of impression in each patient was measured and the mean length for all impressions calculated (in mm). The depth of the impression (in mm) was measured perpendicular to the surface of the articular cartilage of the femoral condyle in sagittal orientation and categorized as follows: I: 0 - < 1 mm; II: 1 - < 2 mm, III: 2 - < 3 mm; IV: 3 - < 4 mm; V: ≥ 4 mm.

Clinical evaluation at re-examination included three different Knee scoring systems (modified Lysholm-Tegner-Activity-Score, Rasmussen's clinical score and modified Cincinnati Rating System Questionnaire) [23–25]. Apart from the time-point at re-evaluation, all patients had to complete the scores retrospectively concerning their immediate post-traumatic status.

2.2. Quantitative analysis

Three cartilage regions of the lateral femoral condyle were analysed in all participants (the anterolateral as well as the bordering anterior and central cartilage, Fig. 1). In patients with a positive DLNS in post-traumatic MRI, maximum length of the impression (in mm) in the anterolateral cartilage was measured. Subsequently, the ROI in the