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Articular cartilage status 2 years after arthroscopic ACL reconstruction in patients with or without concomitant meniscal surgery: evaluation with 3.0T MR imaging

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Abstract
Purpose To assess articular cartilage changes in the knee joint as detected on 3.0T MR imaging after 2-year follow-up in patients who underwent arthroscopic anterior cruciate ligament reconstruction (ACLR) with or without concomitant meniscal surgery.
Methods A total of twenty-nine patients (mean age 30.3 ± 10 years), who underwent arthroscopic ACLR, received clinical and imaging follow-up at an average of 27.8 ± 4.8 months after surgery. Our patients were divided into two subgroups: eighteen patients with additional meniscal injuries at the time of arthroscopic ACLR who underwent meniscal surgery and eleven patients with intact menisci. The cartilage status of all knees at the time of arthroscopic ACLR was recorded. All patients underwent an MRI scan preoperatively and at follow-up with the same imaging protocol. Cartilage status of all knee compartments was evaluated at the time of follow-up by MR imaging and the ICRS classification.
Results Deterioration of the cartilage status was found at all knee compartments of our study group, with respect to the number of cartilage defects. The cartilage of the lateral femoral condyle (LFC) was most severely affected, followed by patellar and medial femoral condyle (MFC) cartilage. A statistically significant relation was found between surgery of the medial meniscus and the development of new cartilage defects in LFC ($p = 0.01$) and MFC ($p = 0.03$) after adjusting for the site of meniscal surgery. The cartilage of LFC and the status of the medial meniscus were also found to be significantly related ($p = 0.04$). Partial meniscectomy was found to be associated with an increased incidence of new cartilage defects when compared to either meniscal repair or absence of meniscal surgery, although it was not statistically significant.
Conclusion Development of new cartilage lesions was evident after 2-year follow-up in patients with arthroscopic ACLR as detected by MR imaging. There was a multicompartmental pattern of cartilage involvement, and the lateral compartment was most severely affected. Partial meniscectomy at the time of arthroscopic ACLR could be suggested as an additional risk factor for the progression of chondral lesions.
Level of evidence Prospective comparative study, Level II.

Keywords Anterior cruciate ligament reconstruction · Cartilage · 3.0T MRI

Introduction

Arthroscopy is an interventional technique that provides conclusive evaluation of the knee cartilage, which is essential among patients with anterior cruciate ligament (ACL) tear and concomitant meniscal injuries [13, 16]. These patients, particularly young and active adults, may require post-operative assessment of the ACL graft and the knee cartilage that is not necessarily symptomatic. In such cases, the evaluation of the post-operative status of the knee in routine clinical practice is performed by magnetic resonance imaging (MRI) with respect to availability and efficacy [21, 43].

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MRI is the most reliable non-invasive imaging method for evaluating morphological changes in the articular cartilage both for initial assessment and follow-up. Cartilage-sensitive MR techniques such as spoiled gradient-echo (SPGR) and fast spin-echo (FSE) sequences with fat suppression are considered to be the standard of reference for morphologic assessment of the knee cartilage due to high accuracy when compared to arthroscopic findings [4, 33]. However, their diagnostic performance appears relatively lower in detecting low-grade cartilage lesions [21, 40, 44]. Advanced MRI techniques such as T2 mapping [24, 32], T1rho [25, 39] and delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) [27] which estimate compositional cartilage parameters including collagen, water and proteoglycan/glycosaminoglycan content have shown a unique ability to quantitatively provide information regarding cartilage quality, but their implementation in routine protocols is still limited.

The ACL reconstructed knee remains in high risk of developing osteoarthritic changes [1, 13, 19, 34] especially in cases with concomitant meniscectomy [7, 8], despite the stabilizing effect of ACL repair. Preservation of the greater part of meniscus and/or meniscal repair has been proposed as the optional treatment options of ACL rupture and concomitant meniscal tears [13, 28] in order to prevent cartilage degeneration.

The working hypothesis of the present study included the evaluation of the knee cartilage in patients with arthroscopic ACLR with or without concomitant meniscal surgery after 2-year follow-up with MR imaging. The study aimed to explore the following points:

1. To investigate the progression and distribution of chondral lesions as detected on MR imaging after 2-year follow-up in our group of patients.
2. To assess whether meniscal surgery is a risk factor for developing cartilage lesions among patients with arthroscopic ACLR and correlate the location and the type of meniscal involvement.

Materials and methods

Twenty-nine patients (mean age 30.3 ± 10 years) of whom 26 were male (mean age 30.8 ± 9.8) and 3 were female (mean age 26.7 ± 13.4 years) were enrolled in the present study. The initial number of patients included in the study group was 34; four patients were excluded due to ACL graft failure and another one due to post-operative infection that resulted in early revision arthroscopy.

All patients underwent clinical and preoperative evaluation with 3.0T MRI in our department between April 2009 and December 2010 and subsequently arthroscopic ACLR. The average period between time from injury and ACLR was 26.2 ± 44.5 months. All patients agreed to have a clinical and imaging follow-up two years after the ACLR. The presence of additional injuries involving menisci and articular cartilage of all three compartments of the knee at the time of ACLR was also recorded. Our patients were further divided in two subgroups with respect to the meniscal status directly after the ACLR. There were 18 patients who underwent concomitant meniscal surgery, either partial meniscectomy (11 patients) or meniscal repair (7 patients), and 11 patients with intact menisci.

The inclusion criteria for a patient to participate in the follow-up investigation were:

1. No additional knee surgery between the ACLR and follow-up
2. No rotational or valgus injury between ACLR and follow-up
3. Patient's agreement to undergo MRI of the knee at follow-up

Demographic data, mean follow-up, time from injury for each subgroup and distribution of meniscal surgery are shown in Table 1a, b.

Informed consent was obtained from all patients, and the study was approved by the Institutional Review Board of the University Hospital of Larissa, Greece (ID number 74, 20.03.2007).

Surgical technique

All patients underwent ACL reconstruction. Semitendinosus/gracilis autograft was used in 27/29 patients; bone–tendon–bone patellar autograft was selectively used in 2/29 female patients. Double-bundle technique was used in 4/29 patients.

Tibial stabilization was achieved using a screw and femoral stabilization using the endobutton technique. Degenerative meniscal tears, white-white zone tears and complex tears were treated with partial meniscectomy. Peripheral meniscal tears (red-red zone and red-white zone) and longitudinal tears were treated with an all-inside suturing technique (FasT-Fix; Smith&Nephew). The number of sutures depended on the tear size. The majority of the operations were performed by the same surgeon. All patients underwent the same ACLR rehabilitation protocol.

Magnetic resonance imaging

All MRI scans were performed at a 3.0T unit (GE Healthcare, Signa HDx) with a quadrature knee coil. The protocol used for detection of ligamentous pathology, meniscal tears and cartilage lesions was identical to the baseline

Table 1 Patients' demographics and data regarding meniscal status

			Overall
a			
Age (years)			30.3 ± 10
Males/females (*n*)			26/3
Time from injury (months)			26.2 ± 44.5
Follow-up (months)			27.8 ± 4.8

	Intact meniscus	Partial meniscectomy	Meniscal repair
b			
Medial meniscus			
Age (years)	29.9 ± 10.5	32.1 ± 11.0	28.6 ± 8.1
Males (*n*)	13	9	4
Females (*n*)	2	0	1
Time from injury (months)	14.3 ± 36.21	44.2 ± 61.4	29.6 ± 80.8
Follow-up (months)	28.1 ± 5.21	27.1 ± 3.75	28.2 ± 6.14
Lateral meniscus			
Age (years)	30.7 ± 10.6	32.0 ± 7.4	22.0 ± 5.6
Males (*n*)	19	5	2
Females (*n*)	3	0	0
Time from injury (months)	19.4 ± 38.9	64.6 ± 59.9	5.7 ± 6.0
Follow-up (months)	28.2 ± 5.3	26.8 ± 2.9	25.5 ± 0.7

examination. This included axial (TR/TE 2500/32, 18-cm FOV, 4-mm slice thickness), coronal (TR/TE 1800/32, 18-cm FOV, 3-mm slice thickness) and sagittal (TR/TE 2300/32, 18-cm FOV, 2-mm slice thickness) proton density-weighted fast spin-echo sequences with fat saturation, coronal T1-weighted (TR/TE 500/8, 18-cm FOV, 3-mm slice thickness) fast spin-echo sequence and 3D-SPGR T1-weighted (TR/TE 12/2.5, 18-cm FOV, 1-mm slice thickness) with fat saturation. The total scanning time was approximately 35 min.

MRI examinations were reviewed by a team of two musculoskeletal radiologists with 10 and 22 years of experience in MR imaging for the presence of ligamentous pathology, meniscal tears and cartilage lesions. The status of the ACL graft was assessed as being intact or failed. The presence of new meniscal tears was also recorded. The articular surfaces of the knee were divided into six regions: patella, trochlea, medial femoral condyle, lateral femoral condyle, medial tibial condyle and lateral tibial condyle. MR grading of the cartilage lesions was based on the International Cartilage Repair Society classification for traumatic cartilage lesions. Normal cartilage was scored as grade 0, and a threshold of 50 % was used for MRI evaluation as follows: grade I for superficial lesions such as fissures and cracks, grade II for lesions involving less than 50 % of the full cartilage thickness, grade III for lesions involving 50–99 % of the full cartilage thickness and grade IV for full-thickness lesions with subchondral bone exposure.

Clinical evaluation

Traumatic incidences between baseline and follow-up were documented. Each participant underwent a detailed clinical assessment of the reconstructed and contralateral knee, and signs of laxity (Lachman test, pivot shift test and drawer signs) and/or meniscal pathology was documented. In addition to that, validated subjective knee questionnaires were completed and compared to the same baseline outcome measures (KOOS, Lysholm and Tegner activity scale) (Table 2).

Statistical analysis

Fisher's exact test was performed to find any associations between meniscal surgery and the site of chondral defects at follow-up. Mixed-effect analysis was used to estimate whether meniscal surgery had an effect on the appearance of chondral defects. The association between time from injury and development of cartilage lesions was also estimated. The difference in the number of lesions for each patient was taken into consideration before and after surgery. Each change was marked as a binary outcome, i.e., yes for a detected change or no if there was not any change. Chi-square test was used to measure any significant difference. Corrections for small sample size were also used.

Results with a *p* value less than 0.05 were considered statistically significant. The R Project for statistical analysis was used to carry out all statistical calculations.

Table 2 Clinical scores of subgroups with respect to the type of meniscal surgery

	Partial meniscectomy		Meniscal repair		No meniscal surgery		Total	
	Preop	Post-op	Preop	Post-op	Preop	Post-op	Preop	Post-op
Lysholm[a]	72	96	79	98.8	84.5	96.7	78.5	97.1
Tegner[b]	5.6	3.9	6.1	4.7	6.4	4.8	6	4.5
KOOS[c]	77.2	96.6	89	96	88	95.4	84.7	96

[a] Lysholm score index

[b] Tegner activity scale

[3] KOOS Knee injury and Osteoarthritis Outcome Score

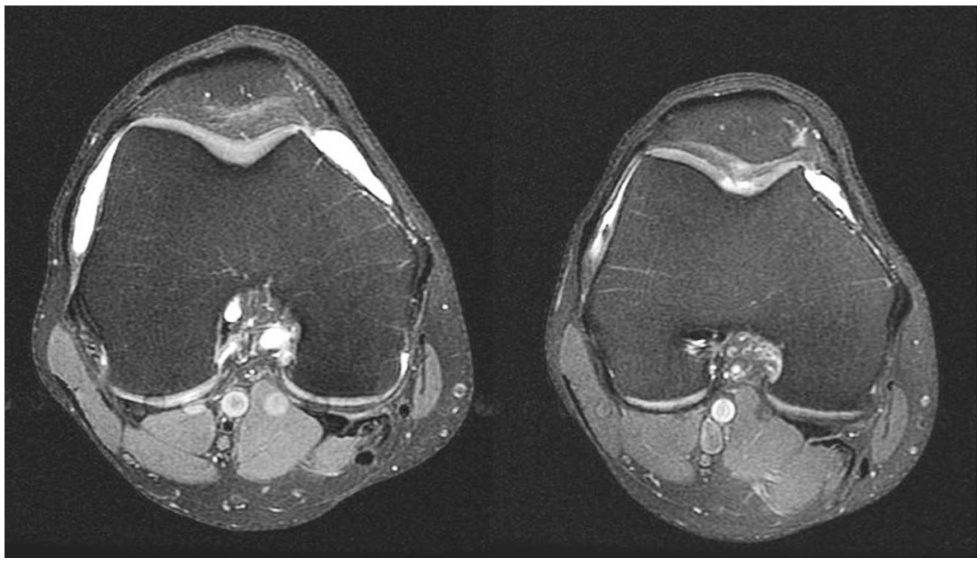

Fig. 1 **a** Axial proton density MR image with fat suppression shows an intact trochlear cartilage. **b** Same patient two years later with cartilage defect at the trochlear groove. This patient underwent ACLR and meniscal surgery

Results

All 29 patients underwent arthroscopic ACLR. Additionally, 11/29 (38 %) underwent surgery of the medial meniscus, and 7/29 (24 %) underwent surgery of the lateral meniscus, either excision or repair; 2/29 (7 %) developed tears in a previously intact meniscus at follow-up.

Cartilage lesions were observed in 19/29 patients (65.5 %) at follow-up compared to 10/29 of patients (34.5 %) at baseline examination ($p = 0.03$). There was a threefold increase in the total number of articular cartilage lesions from baseline (12 cartilage lesions) to follow-up (35 lesions) (Figs. 1, 2). The distribution of chondral lesions can be shown in Table 3. The interobserver agreement was excellent for meniscal tears and ACL grafts (Cohen's kappa = 0.92) and moderate for cartilage defects (Cohen's kappa = 0.63).

A statistically significant association was found between the location of meniscal surgery and the site of chondral defects at follow-up. Patients who underwent medial meniscal surgery were found to have a statistically significant deterioration of cartilage lesions regarding LFC ($p = 0.01$) and MFC ($p = 0.03$), respectively. There was no statistically significant association between lateral meniscal surgery and the site of chondral defects at follow-up.

Regarding the site that was more likely to develop cartilage changes among patients who underwent medial meniscal surgery, LFC was found to be more prone to develop new chondral defects at follow-up when compared to MFC ($p = 0.002$).

Looking at the progression of cartilage lesions after adjusting for the site of surgery, we found that only in the case of LFC, the medial meniscal surgery had a significant effect ($p = 0.04$), although marginal. No statistically significant association was found between the location of meniscal surgery and development of new chondral defects at the patellofemoral compartment.

The progression of cartilage lesions with respect to the type of meniscal surgery, either partial meniscectomy or meniscal repair, is shown in Table 4.

Time from injury did not have any statistically significant effect on the progression of cartilage lesions at the follow-up.

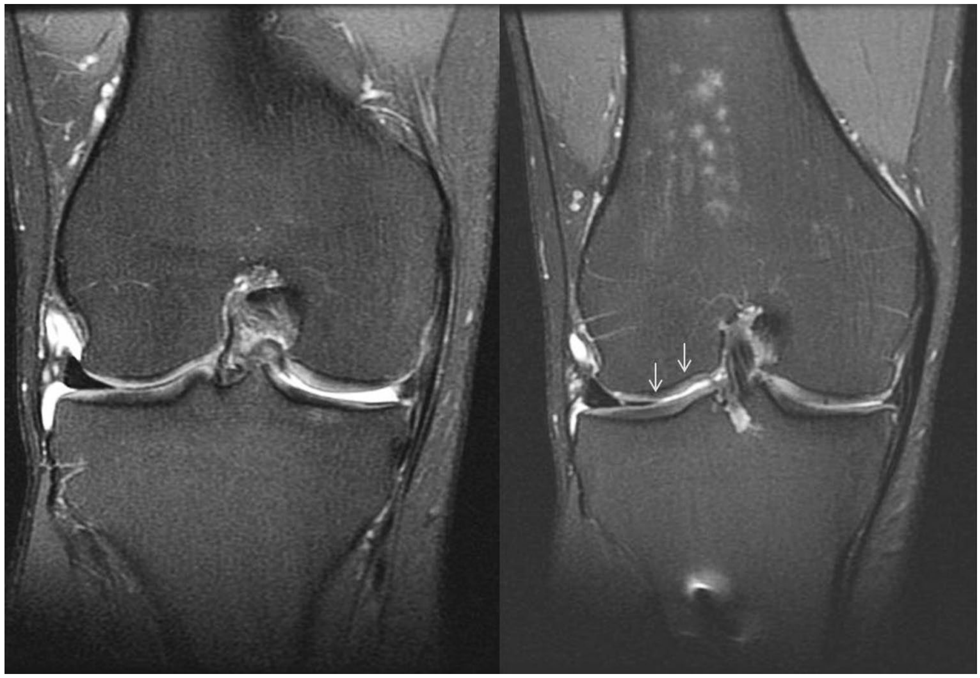

Fig. 2 **a** Coronal proton density MR image with fat suppression shows normal cartilage of both medial and lateral femoral condyle. **b** Same patient two years post-ACLR. The coronal proton density MR image with fat suppression shows definite cartilage defects involving the lateral femoral condyle (*arrows*)

Table 3 Distribution of articular cartilage lesions

Articular surface	Baseline chondral lesions	Follow-up chondral lesions
MFC	7	12
LFC	2	13
MTC	2	2
LTC	0	1
PAT	1	4
TROCH	0	3

The values in the vertical lines depict the number of chondral lesions in each compartment, and the numbers in the horizontal lines show their spread at follow-up. For example, 5 new lesions developed in the MFC

MFC medial femoral condyle, *LFC* lateral femoral condyle, *MTC* medial tibial condyle, *LTC* lateral tibial condyle, *PAT* patella and *TROCH* trochlea

Table 4 Progression of articular cartilage lesions related to the type of meniscal surgery

Subtype of meniscal surgery	Chondral lesions at baseline	Chondral lesions at follow-up
Partial meniscectomy	8	21
Meniscal repair	2	7
No meniscal surgery	2	7
Total	12	35

Discussion

The most important finding of the present study was the increased incidence of LFC cartilage defects as detected on 3.0T MR imaging after 2-year follow-up. The involvement of patellar and MFC cartilage was also evident with a declined incidence of new lesions. Furthermore, patients who underwent partial meniscectomy combined with arthroscopic ACLR were found to have a trend of developing new cartilage defects, although not statistically significant, compared to patients who underwent either meniscal repair or no meniscal surgery.

The progressive loss of articular cartilage thickness after arthroscopic ACLR and the deterioration of cartilage defects with respect to their grade and number are well known in the literature [8, 11, 14, 17, 24, 34, 37, 41, 42]. This was confirmed in this study with 23 new cartilage lesions in a 2-year follow-up when compared to the initial 12 lesions that were detected in our patients during surgery.

Our study showed the development of new cartilage lesions involving the LFC and patella at follow-up that were previously intact. Progression of cartilage defects involving the MFC was also detected with respect to number and grading. This was the location that was most severely affected at the time of surgery. This may suggest that the progression of articular cartilage defects involving the lateral and patellofemoral compartment, compared to the medial compartment, could imply post-operative embiomechanic alterations that deteriorate the cartilage in the above locations. This hypothesis has been supported by a number of studies [2, 14, 39]; Potter et al. [32] studied the progression of cartilage loss in ACLR and non-ACLR knees and reported that the risk for cartilage loss doubled after 1 year for the LFC and MFC and tripled for the patella, whereas between years 7 and 11, the risk for the LFC, when compared to the baseline, increased 50 times, for the patella 30 times and for the MFC 19 times.

However, the above findings appear debatable in the literature, with some studies supporting the notion that the cartilage of the medial compartment is most severely affected post-arthroscopic ACLR [14, 27, 39]. Hosseini et al. [20] measured a consistently greater increase in cartilage deformation in the medial tibiofemoral compartment when compared to the lateral compartment at 6-month follow-up. Additionally, a recent 2- to 4-year follow-up study with quantitative MRI [24] reported higher T2 values, which reflected deterioration of cartilage status in the medial compartment of the knee. A more generalized concept of cartilage loss is supported by Lee et al. [23], who reported progressive cartilage degeneration in 26.7 % of all investigated sites, with the patella medial facet, lateral femur anterior region and medial femur central region showing significantly more cartilage loss than other articular regions.

Biomechanical changes in the reconstructed knee with an increased valgus stress and/or increased loading in the lateral compartment may provide some explanation for this pattern of articular cartilage degradation [35]. Multiple biomechanical analyses almost uniformly postulate that kinematic abnormalities are not eliminated with reconstruction of the ACL [6, 37, 38]. No significant improvements are observed in maximum angular knee flexion excursion during stance, peak knee flexion angle, peak knee flexion moment during walking or maximum external tibial rotation angle throughout the gait cycle [36]. Georgoulis et al. [15] and Ferretti et al. [12] noticed a persistent increased anterior tibial translation combined with rotational changes in reconstructed knees. Additionally, Hosseini et al. [20] linked lack of biomechanics restoration after ACLR to shifts in contact points towards regions of thinner cartilage with increased contact deformation.

Meniscectomy is a significant risk factor for cartilage degradation and for development of radiographic OA among patients with ACLR [1, 9, 10, 19, 24]. This was also evident in our study, since we found that surgery of the medial and not of the lateral meniscus was significantly associated with new chondral lesions in both LFC and MFC ($p = 0.01$ and $p = 0.03$, respectively). Furthermore, LFC was found to be significantly more prone to develop new cartilage defects compared to MFC ($p = 0.002$) in patients who underwent ACLR and surgery of the medial meniscus. However, the detrimental effect of lateral meniscectomy on the articular cartilage post-ACLR is also well established in some studies [7, 31]. A bias regarding our findings may be attributed to the relatively small subgroup of patients who underwent lateral meniscal surgery.

There was also a notable increase in the total number of chondral lesions, although not statistically significant, among patients who underwent partial meniscectomy compared to patients who underwent either meniscal repair or no meniscal surgery. There are reports in the literature in agreement with our findings. Our results agree with the review from Brophy et al. [5], which determines the relation of prior partial meniscectomy and meniscal repair with grade II, III and IV chondral lesions at revision of ACLR. A systematic review from Magnussen et al. [26] found that patients with partial meniscectomy and concomitant ACLR were five times more likely to exhibit radiographic findings of OA when compared to patients having intact menisci after ACLR. Paxton et al. [30] noticed less radiographic degenerative changes in knees post-ACLR and meniscal repair compared to knees post-ACLR and partial meniscectomy. Long-term studies have also shown that successful meniscal repair would provide a chondroprotective effect to the tibiofemoral compartment involved [28]. However, the progression of chondral lesions post-ACLR, even among patients with intact menisci, may indicate the presence of further pathogenetic mechanisms such as inflammatory biomarkers involved in the degradation of cartilage post-ACL injury and possibly after ACLR [3, 18, 22, 29].

There are some limitations in the present study. Arthroscopic ACLR procedures varied among patients, a factor that could be independently related to the progression of cartilage lesions. In addition to that, we had a small number of participants and this becomes more obvious when analysing the subgroups of patients with respect to their meniscal status during ACLR. Another limitation is the lack of second-look arthroscopy for the evaluation of the articular cartilage, as arthroscopy remains the gold standard for detection and grading of chondral lesions. Nevertheless, arthroscopy remains an invasive procedure and therefore not easily applicable at follow-up studies, if it was not clinically justified. Regarding imaging, we have not applied a more advanced technique such as T2 mapping due to limited availability and increased scanning time.

The implementation of newer techniques regarding ACLR reconstruction that were used in our study group combined with meniscal surgery when necessary has not prevented post-operative cartilage changes. So far, no graft has been shown to re-establish normal kinematics of the knee joint after arthroscopic ACLR.

Conclusion

The development of new cartilage lesions was evident after 2-year follow-up in patients with arthroscopic ACLR, as detected by MR imaging. There was a multicompartmental pattern of cartilage involvement, and the lateral compartment was the most severely affected. Partial meniscectomy of the medial meniscus appeared to be a risk factor for the progression of chondral lesions.

Compliance with ethical standards

Conflict of interest None.

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