

Total resection of any segment of the lateral meniscus may cause early cartilage degeneration

Evaluation by magnetic resonance imaging using T2 mapping

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Abstract

The aim of this study was to perform quantitative evaluation of degeneration of joint cartilage using T2 mapping in magnetic resonance imaging (MRI) after arthroscopic partial resection of the lateral meniscus.

The subjects were 21 patients (23 knees) treated with arthroscopic partial resection of the lateral meniscus. MRI was performed for all knees before surgery and 6 months after surgery to evaluate the center of the lateral condyle of the femur in sagittal images for T2 mapping. Ten regions of interest (ROIs) on the articular cartilage were established at 10-degree intervals, from the point at which the femur shaft crossed the lateral femoral condyle joint to the articular cartilage 90° relative to the femur shaft. Preoperative and postoperative T2 values were evaluated at each ROI. Age, sex, body mass index, femorotibial angle, Tegner score, and amount of meniscal resection were evaluated when the T2 value increased more than 6% at 30°.

T2 values at approximately 10°, 20°, 30°, 40°, 50°, and 60° degrees relative to the anatomical axis of the femur were significantly greater postoperatively (3.1, 3.6, 5.5, 4.4, 5.0, 6.4%, respectively) than preoperatively. A >6% increase at 30° was associated with total resection of any segment of the meniscus.

Degeneration of the articular cartilage, as shown by the disorganization of collagen arrays at positions approximately 10°, 20°, 30°, 40°, 50°, and 60° relative to the anatomical axis of the femur, may start soon after arthroscopic lateral meniscectomy. Total resection of any segment of the lateral meniscus may cause T2 elevation of articular cartilage of lateral femoral condyle.

Abbreviations: 3T = 3 tesla, BMI = body mass index, FOV = field of view, FTA = femorotibial angle, ICC = interclass correlation coefficients, KL = Kellgren–Lawrence, MRI = magnetic resonance imaging, ROIs = regions of interest, SD = standard deviation, TSE = turbo spin echo.

Keywords: arthroscopic lateral meniscectomy, articular cartilage, cartilage evaluation, T2 mapping

1. Introduction

The meniscus is a fibrocartilage that covers the margins of the medial and lateral tibial joints. The meniscal margins are cuneate and thick. The meniscus functions to improve the safety of the articular surface and disperse or absorb mechanical stress associated with walking and knee bending. Total meniscectomy is likely to lead to the development of osteoarthritis over a long period.^[1] The mechanical characteristics of the medial and lateral meniscus are distinct from each other, due to anatomical and

structural differences. The meniscus is generally semi-circular, and the anteroposterior diameter is shorter for the lateral meniscus than the medial one. The meniscus moves forward when extending the knee and backward while bending the knee. The movement distance of the lateral meniscus is longer than that of the medial one. The load to the articular cartilage in the lateral meniscus is likely to increase and cause injury earlier after meniscectomy in comparison with that in the medial meniscus. However, it has not been clarified how much resection of the meniscus would affect the articular cartilage.

The articular cartilage consists of water and extracellular matrix, which is comprised of water, collagens, and proteoglycans. Collagens are evenly aligned, and this alignment maintains the form of the cartilage and inhibits the movement of water molecules within the cartilage. Recently, degeneration of articular cartilage can be evaluated by 3 tesla (3T) magnetic resonance imaging (MRI) or ultrasound.^[2,3] The alignment of collagen and water content in articular cartilage can be evaluated by T2 mapping using 3T MRI.^[4–10] T2 mapping has been used to evaluate quantitative changes in articular cartilage soon after arthroscopic medial meniscectomy.^[11] Regions of interest (ROIs) were set at 10-degree intervals relative to the axis of the femur shaft. This method confirmed irregular collagen alignment and increased water content at points of bending, located 20°, 30°, 40°, and 50° relative to the femur shaft, and was particularly effective at showing marked changes at 30°.

The lateral meniscus enhances the safety of the articular surface and disperses or absorbs mechanical stresses associated with

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We declare that there are no conflicts of interest.

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walking and knee bending. Significant changes in contact pressure on the articular cartilage have been observed after meniscectomy. We hypothesized that load on the articular cartilage in the lateral meniscus may result in more severe injury soon after meniscectomy, and that the range of resection of the meniscus is related to the degree of early cartilage degeneration. The objectives of this study were to quantitatively evaluate changes in articular cartilage from before to 6 months after arthroscopic partial lateral meniscectomy, and to clarify the relationship between early cartilage degeneration and meniscal resection.

2. Materials and methods

This study was approved by the Institutional Review Board of our institution (ERB-C210-1). Informed written consent was obtained from all participants included in the study.

2.1. Subjects

This study enrolled 21 patients with 23 knees. The inclusion criteria were patients who underwent partial lateral meniscectomy for white zone meniscus tears between February 2011 and July 2015. The exclusion criteria were as follows: patients with knee ligament injury or other complications, patients with a knee that showed The International Cartilage Repair Society (ICRS) grade III or IV degeneration in the lateral compartment of the femorotibial joint, and patients who did not undergo MRI both before and 6 months after operation. The 21 patients included 4 males (4 knees) and 17 females (19 knees), with 16 patients (17 knees) exhibiting lateral discoid meniscus. Patients' demographic data are summarized in Table 1. There were 5 types of meniscal tears (vertical, horizontal, degenerative, radial, and discoid meniscus). Degeneration of the articular cartilage during surgery was evaluated by ICRS classification. Only 1 knee showed grade IV degeneration in the patellofemoral joint, with all other knees showing grade 0, I, or II degeneration (Table 2). Partial meniscectomy procedures were performed by 2 experienced orthopedic surgeons under the supervision of the director of Sports Orthopaedics. The amount of meniscus resection was evaluated according to the classification of Hulet.^[12] In the McMurray test, all subjects were positive before surgery, but became negative after surgery. One subject (one knee) continued to experience slight pain 6 months after surgery, whereas all others showed disappearance of pain.

2.2. T2 mapping

All knees underwent 3T MRI (Achieva 3.0T X-series, 8-channel knee coil; Philips Healthcare, the Netherlands) before and 6 months after partial lateral meniscectomy. Imaging protocol included T2 value measurement method, turbo spin echo (TSE) multi-echo time (TE); repetition time (TR), 2000 ms; TE, 15/30/

Table 1

Pre- and intraoperative patient characteristics.

Characteristic	Patients (n=23)
Demographic data	
Male, no. (%)	4 (17.4)
Age at surgery, mean±SD, y	40.3±19.8
Right knee involved, no. (%)	10 (43.5)
Height, cm	156.2±7.4
Weight, kg	52.1±10.4
Preoperative Tegner activity scale	3.8±2.3
History of trauma, no. (%)	2 (8.7)
History of smoking, no. (%)	2 (8.7)
Preoperative knee score	75.9±10.2
Preoperative femorotibial angle, °	175.3±3.5
Duration of surgery, min	46.3±13.0
Type of meniscal tear, no. (%)	
Vertical	9 (39.1)
Horizontal	12 (52.2)
Degenerative/complex	10 (43.5)
Radial	5 (21.7)
Discoid meniscus	17 (73.9)
Postoperative knee score	94.6±5.2

45/60/75/90 (ms); scan time, 5 minutes 22 seconds; sensitivity encoding reduction factor, 2; phase encoding direction, AP; bandwidth, 292.1 Hz (1.48 pixels); field of view (FOV), 160 × 160 (mm); slice thickness, 2.5 mm; and a 384 × 313 matrix. All T2 mapping images were calculated and generated from multiple TE images on MR scanner console software.

To evaluate the relationship between the extent of partial resection of the lateral meniscus and the degeneration of cartilage of the lateral femoral condyle, the sagittal plane in the center of the lateral femoral condyle was assessed on T2 mapped images (Fig. 1). Ten ROIs on the articular cartilage were established at 10-degree intervals, from the point at which the femur shaft crossed the lateral femoral condyle joint to the articular cartilage 90° relative to the femur shaft, as described (Fig. 2).^[11] The depth of each ROI was set to encompass both the superficial and intermediate zones. To avoid partial volume effects, ROIs were set a few pixels from the surface of the articular cartilage, and the difference in each T2 ROI from before to after the operation was determined. To confirm that arthroscopic surgery or the interval of each MRI scan had no effect on cartilage degeneration, T2 values of the articular cartilage in the anterior condyle of the femur were compared before and after surgery. T2 values were quantified by using OsiriX imaging software (OsiriX Foundation, Switzerland). All measurements were performed blindly and independently by 2 orthopedic surgeons specializing in knees, with 8 and 14 years of experience, respectively. The mean T2 and changes in T2 from before to after the operation were determined using Philips MR console software (Philips Medical Systems, Best, Netherlands).

Table 2

Joint cartilage changes noted at surgery (number of patients).

Knee compartment	Grading of cartilage damage according to ICRS classification				
	0	1	2	3	4
Lateral compartment	15	1	7	0	0
Medial compartment	18	1	4	0	0
Patellofemoral compartment	15	1	6	0	1

ICRS = The International Cartilage Repair Society.

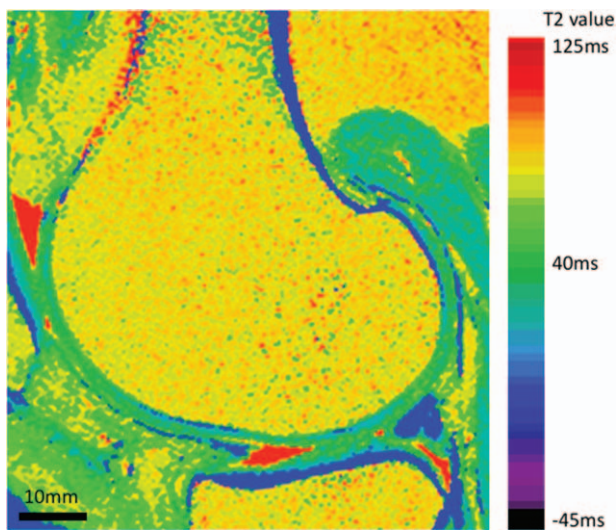


Figure 1. Sagittal cross-section by magnetic resonance imaging (MRI) T2 mapping of the central part of the lateral condyle of the femur. Two layers were visible, the superficial/intermediate layer and the deep layer.

To investigate the effects of patient background: age, sex, body mass index (BMI), femorotibial angle (FTA), Tegner score, variations in meniscal tear and extent of resection on femoral cartilage, the femoral condylar cartilage at 30° was analyzed. This ROI represents the cartilage of the lateral femoral condyle not covered by the anterior and posterior segments of the lateral meniscus. T2 values have been reported to be increased mostly at the 30-degree ROI, with an average increase of 6%, following resection of the medial meniscus.^[11] Therefore, the cut off T2 value for cartilage degeneration was set at an increase of 6%; knees with T2 values at 30° >6% and <5% higher postoperatively than preoperatively were defined as the moderate and mild degeneration groups, respectively. Age, gender distribution, BMI, FTA, Kellgren–Lawrence (KL) classification of the lateral

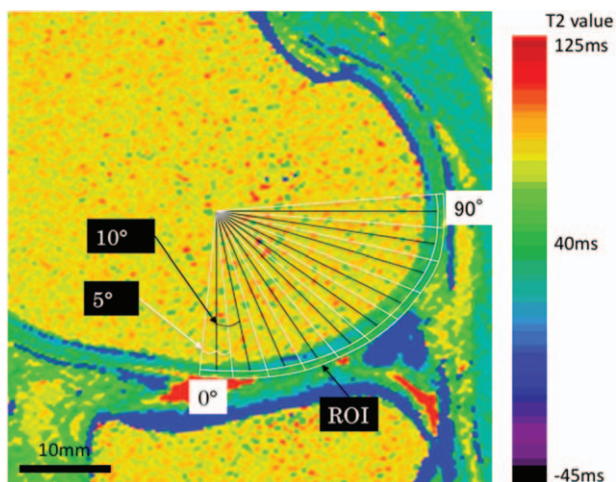


Figure 2. Evaluation points. Ten points were set at 10-degree intervals along the articular surface between the point of intersection of the anatomical axis of the femur and the articular surface of the lateral condyle and the posterior area at approximately 90° relative to the anatomical axis. Regions of interest (ROIs) were set with their centers at these points. The depth of each ROI in the articular cartilage was set to encompass both the superficial and intermediate layers.

femorotibial joint, Tegner activity score, variations in the meniscal tear, and total excision of the meniscal segment were compared in these 2 groups.

2.3. Statistical analysis

Results are expressed as the mean±standard deviation (SD) and were compared by paired *t* tests. Intraclass correlation coefficients (ICCs) were calculated with a 2-way random model. All statistical analyses were performed using SPSS (version 21.0 for Windows; IBM, Chicago, IL), with *P* < .05 defined as statistically significant. Patient characteristics, operation time, and blood loss were compared in knees with and without degeneration using Mann–Whitney *U* tests. Variations in meniscal tears and the occurrence or nonoccurrence of total excision of the meniscal segment were assessed by χ^2 tests.

3. Results

Preoperatively, mean T2 increased gradually from 0° to 50° relative to the femur shaft, peaking at 50°. The mean T2 after the operation increased similarly, but reached a peak at 60°. The postoperative T2 was significantly longer than the preoperative T2 at all ROIs, including at 10° (51.8±4.63 vs 53.4±3.74 ms; *P*=.003), 20° (52.2±3.74 vs 54.1±4.50 ms; *P*=.022), 30° (52.7±4.25 vs 55.7±4.05 ms; *P*<.001), 40° (53.8±4.41 vs 56.1±4.05 ms; *P*=.001), 50° (54.1±4.23 vs 56.8±4.30 ms; *P*=.011), and 60° (53.5±3.60 vs 56.9±4.53 ms; *P*=.002), relative to the femur shaft (Fig. 3). The T2 value in the anterior condyle of the femur, however, was similar before and after surgery (4.7±4.6 vs 44.7±4.9 ms, *P*=NS). The interobserver reliability of the 2 orthopedists for measurement of T2 was 0.811. The intraobserver reliabilities of Observers 1 and 2 were 0.838 and 0.721, respectively.

There were no significant differences in age, gender, BMI, preoperative FTA, Tegner activity score, and variation of meniscal tear between the groups of knees showing moderate and mild degeneration (Table 3). The resected parts of the meniscus are shown in Fig. 4. Total resection of the meniscal segment was more frequent in the moderate (8 knees) than in the mild (1 knee) degeneration group.

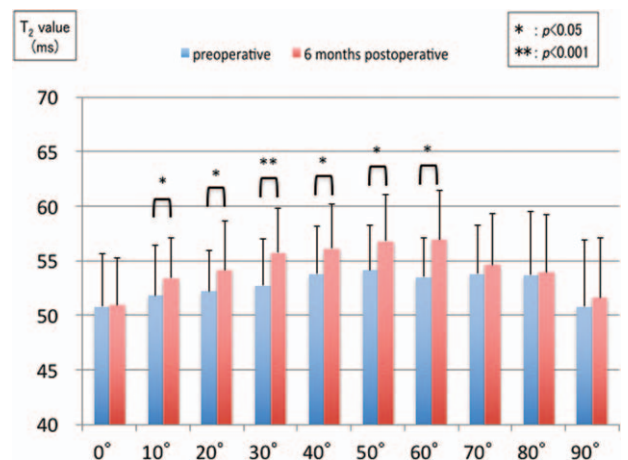


Figure 3. T2 values of regions of interest (ROIs) preoperatively and 6 months postoperatively. T2 values were significantly longer at angles of approximately 10° to 60° relative to the anatomical axis of the femur. Error bars indicate standard deviations (SD).

Table 3**Comparison of patients with or without cartilage degeneration.**

	Degeneration group (n=12)	No degeneration group (n=11)	P
Age, y	35.6±21.0	45.4±18.0	.20
Sex	male 2 female 10	male 1 female 10	.64
BMI, kg/m ²	20.4±2.9	22.2±3.5	.34
Preoperative FTA, °	174.7±3.6	176.1±3.4	.19
Preoperative Tegner score	4.6±2.3	2.9±2.0	.08
Variation of tear (n)			
Vertical	5	4	
Horizontal	6	6	
Degenerative/complex	4	6	
Radial	3	2	
Total resection of any segment (n)	8	1	<.01

BMI = body mass index, FTA = femorotibial angle.

4. Discussion

The important findings in this study are that the degeneration of the articular cartilage, as shown by the disorganization of collagen arrays at positions approximately 10°, 20°, 30°, 40°, 50°, and 60° relative to the anatomical axis of the femur, may start soon after arthroscopic lateral meniscectomy. And total resection of any segment of the lateral meniscus may cause T2 elevation of articular cartilage of lateral femoral condyle.

T2 measured by T2 mapping is the longest when the direction of collagen alignment is 54.7° relative to the direction of the static magnetic field, a phenomenon called the magic angle effect. Normal cartilage may also be considered degenerated due to the magic angle effect.^[13] Furthermore, this study found that T2 before and after the operation was longest at 50° and 60°, respectively, suggesting the magic angle effect. However, the difference in T2 at a given site in any patient was relatively unaffected by the magic angle effect, with differences in T2 at a given site depending on effects other than positional factor.^[14] Arthroscopic partial lateral meniscectomy was considered the

major effector of T2 changes in the articular cartilage from before to after surgery.

Similar to the articular cartilage, the meniscus plays an important role in relieving load on the knee joint. After meniscal resection, the stress on the articular cartilage becomes excessive and cartilage degeneration may occur. We evaluated the short-term effects of arthroscopic medial meniscectomy on articular cartilage using T2 mapping with 3T MRI. These evaluations confirmed that collagen alignment was irregular and water content was increased at the points of bending, located 20°, 30°, 40°, and 50° relative to the femoral shaft, especially at the 30-degree point.^[9] This study also used T2 mapping with 3T MRI to assess the influence of resection of the lateral meniscus on the lateral condylar cartilage of the femur, finding that T2 at points located approximately 10°, 20°, 30°, 40°, 50°, and 60° relative to the femoral shaft were significantly longer after than before meniscectomy. Moreover, irregular collagen alignment and increased water content were observed in these regions after arthroscopic lateral meniscectomy. Taken together, these findings showed that partial resection of the lateral meniscus results in marked degeneration of cartilage in the femur, unlike resection of the medial meniscus. Because the tibial plateau in the lateral compartment is convex, stress on local femoral cartilage may increase. In addition, the load buffer functions of the medial and lateral menisci differ, with the lateral meniscus supporting a higher proportion of load dispersion than the medial meniscus. The lateral meniscus was shown to support approximately 70% of load dispersion, while the medial meniscus supported approximately 50%.^[15] Using cadaveric knees, the peak contact stresses in walking was found to be on the articular cartilage surface in the medial tibial condyle and on the meniscus in the lateral tibial condyle.^[16] Consequently, meniscectomy of the medial and lateral menisci has different effects on the site to be loaded. For example, total medial meniscectomy was found to reduce contact area by 50% to 70% and increase contact pressure 2-fold, whereas total lateral meniscectomy reduced contact area 40% to 50% and increased contact pressure 3- to 4-fold.^[17] Because stress distribution on the meniscus is higher in the lateral than the medial compartment, resection of the lateral meniscus reduces cartilage protection. Moreover, the stability function of the medial and lateral menisci differs. In normal knee kinematics, medial pivot motion occurs with knee flexion or extension. The finding that lateral meniscectomy increases translation and rotation and the pivot shift, indicates that the lateral meniscus plays a major role in the pivot-shift maneuver. Meniscectomy results in abnormal mobility of the lateral condyle, resulting in cartilage degeneration.

Osteoarthritis has been found to progress more after resection of the lateral than of the medial meniscus.^[18–22] X-ray images after resection of the lateral meniscus has shown osteoarthritis in 38% to 84% of knees.^[12,18,23,24] Age >40 years, obesity (BMI > 30 kg/m²), lower limb alignment (valgus knee), and cartilage degeneration during initial arthroscopy were found to be risk factors for osteoarthritis after resection of the lateral meniscus.^[12] Moreover, the risk of OA is higher after total than partial resection of the meniscus,^[22] with stress being positively associated with the extent of meniscal resection, particularly following total resection of the meniscus with the 3D finite element knee model.^[25] Many of the knees in our study with moderate degeneration had undergone total excision of segments of the lateral meniscus. These findings indicated that collagen degeneration of the meniscus starts soon after total resection of any meniscal segment. Type I collagen is predominant (80% by

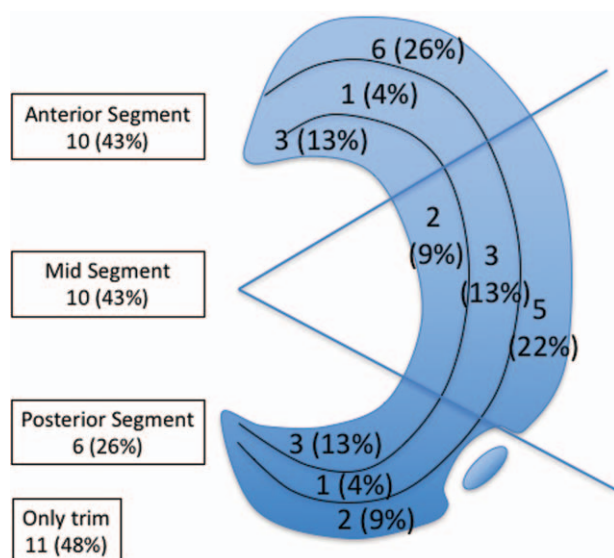


Figure 4. Location of the tears according to the 3 segments of the lateral meniscus.

dry weight) at the margin of the meniscus. Type 1 collagen fibers are oriented circumferentially and play an important role in hoop function. Resection of any segment of the meniscus to its margins reduces hoop function, possibly causing early degeneration of articular cartilage. Partial resection of the lateral meniscus may require repair, even if partial, to prevent resection of the margin of the segment.

This study had several limitations, including the small number of patients and the lack of a control group and control areas. Only evaluation of collagen was performed in this study. The articular cartilage consists of water and extracellular matrix, with the latter comprised of water (70%), collagens (20%), and proteoglycans (10%). MRI quality assessment of the articular cartilage includes the T1rho mapping method and delayed phase cartilage MRI to evaluate proteoglycans.^[26–34]

5. Conclusion

The T2 mapping method was used to quantitatively evaluate articular cartilage shortly after partial lateral meniscectomy. T2 measurements at 10°, 20°, 30°, 40°, 50°, and 60° degrees relative to the femoral shaft were significantly longer post-operatively than preoperatively. Resection to the margin of any segment of the meniscus may cause early degeneration of cartilage.

Author contributions

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