T2 Mapping Values in Postmeniscectomy Knee Articular Cartilage after Running: Early Signs of Osteoarthritis?

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Abstract

Loading on the joints during running may have a deleterious effect on post–partial meniscectomy knee cartilage, leading to osteoarthritis. Utilizing T2-mapping measurements before and after running may enable the observation of changes in the articular cartilage of the postmeniscectomy knees compared with healthy knees. After medial partial meniscectomy, 12 volunteers underwent magnetic resonance imaging (MRI) of the both knees, before and immediately after 30 minutes of running. Quantitative assessment of articular cartilage was performed using a T2-mapping technique. In the medial compartment of the operated knees, significantly lower T2 values were found in anterior tibial plateau (pre- vs. postrun: 33.85 vs. 30.45 ms; $p = 0.003$) and central tibial plateau (33.33 vs. 30.63 ms; $p = 0.007$). Similar differences were found in lateral regions of central femur (post- vs. prerun: 35.86 vs. 40.35 ms; $p = 0.015$), posterior femur (34.89 vs. 37.73 ms; $p = 0.001$), and anterior tibia (24.66 vs. 28.70 ms, $p = 0.0004$). In lateral compartment, postrun values were significantly lower in operated compared with healthy knees, in central femur (34.89 vs. 37.59 ms; $p = 0.043$), posterior femoral (36.88 vs. 39.36 ms; $p = 0.017$), anterior tibia (24.66 vs. 30.20 ms; $p = 0.009$), and posterior tibia (28.84 vs. 33.17 ms; $p = 0.006$). No statistical difference was found while comparing postrun to prerun healthy knees. Lower T2 values were found in operated knees after 30 minutes of running. These changes were seen in medial and lateral compartments. We suspect that running may subject the articular cartilage to excessive loads in the post–partial meniscectomy knee, loads that in healthy knee do not cause any changes.

Keywords
► knee cartilage
► partial meniscectomy
► T2 mapping
► osteoarthritis
► running

Osteoarthritis (OA) is a musculoskeletal disorder and a major disabling condition among the elderly population. Around 9.3 million adults in the United States suffer from OA. It is a multifactorial progressive degenerative joint disease eventually causing functional disability. Articular cartilage is a composite of chondrocytes (1–4%) and extracellular elements including water (60–85%), collagen fibers (10–20%), and proteoglycans (5–10%). The alterations in osteoarthritic cartilage include manifold compositional and structural changes.[1] At the molecular level, there is degradation of

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the collagen–proteoglycan complex, including alterations of the collagen fibrils, disorganization of the collagen network, collagen depletion (advanced stage of degeneration), proteoglycan matrix breakdown, and proteoglycan depletion.

The ability of a healthy cartilage to resist compression is optimal, as the water flow can dissipate most of the energy imparted onto the tissue during compression. At the initial phases of OA, water content of cartilage increases due to various events as follows: exposure of water binding molecules on the collage fibrils; proteoglycan complex breakdown with a higher rate of nonaggregated proteoglycan complexes, resulting in a more penetrable extracellular matrix; reduced tensile stiffness of the degraded collagen network leading to decreased resistance to the osmotic swelling; and temporary reactive increase in the net rate of the proteoglycan synthesis.

Thus, in the degenerative cartilage[2] present in early OA, water movement becomes less restricted and more of the compression force is imparted to the collagen and to the aggrecan matrix, leading to further degeneration. With the progression of the collagen network degradation and the depletion of proteoglycan, the cartilage water content eventually decreases. Transient loading forces associated with running, actually decrease the T2 relaxation times, due to increased water mobility after altered proteoglycan morphology.

Magnetic resonance imaging (MRI) has evolved into being the most valuable tool for assessing the degree and extent of degenerative changes in the articular cartilage.[3–5] T2 is the spin-spin relaxation time, which reflects interactions between water protons, water and the macromolecular concentration, and structures of the extracellular matrix (ECM). T2-mapping measurements enable the detection of small alterations in the water content, as well as variations in the structural integrity of collagen, and the proteoglycans.[6] Using these methods facilitates the identification of cartilage changes and damage at the earlier stages of OA.[7]

Running has many benefits:[8,9] it has been shown to control blood pressure, levels of lipids and cholesterol, as well as improving cardiovascular endurance.[8,10] It is useful for weight management and can improve strength endurance and mood. Despite of all the positive attributes, the loading on the joints during running may have a deleterious effect on the joint cartilage leading to OA.[11,12] Biomechanically, cartilage can be viewed as an intra-articular shock absorber which dampens physiologic loads, transfers the applied load to the subchondral bone, and reduces friction in the joint.[13] The meniscus, that is, responsible for shock absorption, load transmission, and stability within the knee joint, plays a crucial role in maintaining knee cartilage integrity.[14] Meniscal tear, usually the medial meniscus, is a common sport injury. Partial meniscectomy is a common orthopaedic surgical procedure. Most patients undergoing partial meniscectomy are young and active adults, seeking to return to their sport activities.[15,16]

The effect of running on the knee joint articular cartilage in the post–partial meniscectomy state has yet to be investigated. The goals of this study were to analyze and compare the changes in the joint cartilage before and after running 30 minutes on a treadmill, in the normal and post–partial meniscectomy knees of young healthy adults. We hypothesized that utilizing T2-mapping measurements, before and after running, will enable the observation of changes in the articular cartilage of the postmeniscectomy knees compared with healthy knees. This may be of help in revealing the effect of running on the postmeniscectomy knee joint cartilage, thus facilitating the guidance of our patients regarding the possible return to sport and running.

Materials and Methods

Patient Population

All research was reviewed and approved by our local institutional review board (IRB), and informed consent was received from all participants. The study included a group of adult volunteers aged 19 to 33 years (mean ± standard deviation [SD]: 27 ± 4.66; ►**Table 1**). Twelve volunteers were recruited from a group of patients who underwent arthroscopic partial meniscectomy in our medical center between the years 2011 and 2015. Women were not included to prevent a potential confounding effect due to sex hormone on cartilage or gender differences in knee biomechanics. All patients provided informed consent after receiving a full explanation of the nature of the study. Demographic data collected at the time of the MRI study included age, height, and weight. Body mass index (BMI) was calculated by dividing the weight in kilograms by the square of the height in meters. Exclusion criteria were: previous knee surgery, injury or pathology other than meniscal tear (patients with low-grade cartilage pathology [International Cartilage Repair Society (ICRS) Cartilage Lesion Classification System - grade 1 and 2] were included), knee pain during daily activity, or inability to run for 30 minutes, any pathology or surgery to the contralateral knee.

MRI of the two knee joints of all volunteers was performed. All MRI scans were done during morning (a.m.) hours during 2016. Volunteers were instructed to arrive at 08:00 from home, without doing any physical activity. Participants underwent prerun MRI with T2 mapping of both knees. Immediately after the prerun scan, the participants were examined for signs of instability, meniscal injuries, and other pathologies in the knees (►**Table 2**). Within 30 minutes after completing the prerun scan, they were then instructed to jog on a treadmill as fast as possible, for 30 minutes. During the run, the participants were supervised by the coauthor C.Y. of the paper, who encouraged them to run as fast as they can. All 12 participants finished the 30-minute run. Distance completed was between 4.3 and 6.6 km, with average of 4.96 ± 0.66 km (►**Table 2**). Within 15 minutes after finishing the jog, participants underwent the postrun MRI with T2 mapping of both knees (►**Fig. 1**). The prerun scan included T1, T2, and T2 mapping, while the postrun scan included only T2 mapping.

MRI Scans

Multi echo spin echo (MESE) scans were performed on a 3-T MR scanner (Skyra, Siemens Healthineers Inc., Erlangen, Germany) using a 15-channel dedicated knee coil.

Table 1 Subject demographic data and information from past arthroscopic surgery

Subject	Age (y)	BMI (kg/m^2)	Operated side	Diagnosis	Arthroscopic surgery type	ICRS level
1	22	27.40	Left	Medial meniscal tear	Partial meniscectomy	0
2	28	23.15	Left	Medial meniscal tear	Partial meniscectomy	1A patella only
3	26	28.39	Left	Medial meniscal tear	Partial meniscectomy	0
4	21	20.50	Left	Medial meniscal tear	Partial meniscectomy	0
5	24	22.15	Left	Medial meniscal tear	Partial meniscectomy	1b MTP + MFC
6	25	32.24	Left	Medial meniscal tear	Partial meniscectomy	0
7	34	27.82	Right	Medial meniscal tear	Partial meniscectomy + plica removal	0
8	31	25.83	Left	Medial meniscal tear	Partial meniscectomy	2 MTP only
9	24	19.37	Left	Medial meniscal tear	Partial meniscectomy	2 patella only
10	35	22.60	Right	Medial meniscal tear	Partial meniscectomy	0
11	32	24.98	Right	Medial meniscal tear	Partial meniscectomy	1b MTP
12	26	24.45	Right	Medial meniscal tear	Partial meniscectomy	0

Abbreviation: BMI, body mass index; ICRS, International Cartilage Repair Society; MFC, medial femoral condyle; MTP, medial tibial plateau.

Experimental parameters were: TR (repetition time) = 1,100 ms, TE (echo time) = 15, 30, 45, 60, 75, and 90 ms, field of view = 160 × 160 mm^2, matrix size = 384 × 384, slice thickness = 7 mm, 11 slices. Sagittal images of the medial and the lateral femorotibial joints were acquired. Each patient's dataset included four series of images. Series 1: operated knee prerun; series 2: operated knee postrun; series 3: healthy (nonoperated) knee prerun; and series 4: healthy (nonoperated) knee postrun.

Data Postprocessing

Quantitative T2 maps (see an example in ►**Fig. 2**) were generated using echo modulation curve algorithm (Ben-Eliezer et al).[17] All fitting procedures were programmed in-house using C + + and MATLAB (The MathWorks Inc., Natick, MA).

MRI Analysis

A musculoskeletal radiologist (coauthor) examined the MRI scans of all participants for pathologies. Six regions of

Table 2 Subject physical examination data

Patient	Range of motion		Thigh circumference (in cm)		Effusion	Instability	Meniscal test results	Distance ran (in Km)
	Extension	Flexion	After surgery	Control				
1	Normal	Normal	52	52	Negative	No	Negative	5.3
2	Normal	Normal	43.5	44.5	Negative	No	Slight medial space sensitivity and positive McMurry's value in operated knee	4.3
3	Normal	Normal	53	52	Negative	No	Negative	4.6
4	Normal	Normal	43	45	Negative	No	Negative	6.6
5	Normal	Normal	47.5	49	Negative	No	Slight positive in operated knee (McMurry)	5.1
6	Normal	Normal	62.5	61.5	Negative	No	Negative	5.6
7	Normal	Normal	55	54	Negative	No	Negative	4.5
8	Normal	Normal	46.5	48.5	Negative	No	Negative	5.1
9	Normal	Normal	43.5	45	Negative	Slight positive Lachman's score in operated knee	Slight positive in operated knee (McMurry)	4.5
10	Normal	Normal	43	43	Negative	No	Negative	4.7
11	Normal	Normal	49	49.5	Negative	No	Negative	4.3
12	Normal	Normal	49	47	Negative	No	Negative	5.1

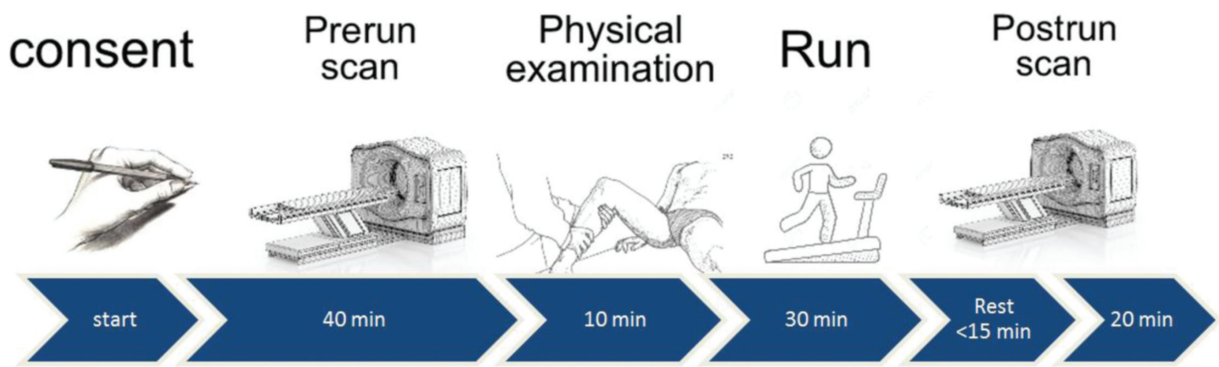

Fig. 1 The study flow chart—informed consent, prerun scan, physical examination, 30-mintue run, and postrun scan within 15 minutes of run finish.

interest (ROIs) were manually segmented by a trained orthopaedic surgeon (coauthor, postgraduate year [PGY] 4), supervised by musculoskeletal radiologist. Segments covered medial and lateral weight-bearing parts of the cartilage (►**Fig. 3**). Superior and inferior surfaces of the cartilage were each divided into three regions using the inner margin of the meniscus as a marker for the anterior and posterior borders of the weight-bearing regions (►**Fig. 4**). The four sagittal sections were selected out of 11 available sections, chosen to represent central areas of medial and lateral parts of the knee joint, as shown in ►**Fig. 5**. Thus, a series of 4 × 4 images were analyzed for each participant, with each image containing six ROIs, for a total of 1,152 ROIs across the 12 patients. A representative set of ROIs for a single lateral–sagittal slice is illustrated in ►**Fig. 3**. The mean ± 3 SDs of T2 values were calculated in each ROI, after excluding outlier values using Chauvenet's criterion with 3 SDs.

Results

For medial and lateral part of each knee, two sagittal images were selected (►**Table 3**). These images had to resemble anatomically to slices shown in ►**Fig. 5**. It was found that, it is more statistically appropriate to analyze the mean T2 value of the two slices in each knee part, than each slice separately due to the number of participants. Therefore, the mean T2 values of two chosen medial slices and the two chosen lateral slices of each knee were calculated and used in the final analysis (►**Table 4**). The mean value was corrected by using the number of pixels in each ROI (proportional to the number of pixels in the ROI). We think that, this represents more appropriately the results. ROIs that were anatomically inconsistent or with too much noise were excluded from the analysis. The number of regions that were used in the final analysis is shown in ►**Table 3**.

A paired *t*-test was performed. Operated prerun knee, operated postrun knee, healthy (nonoperated) prerun knee, and healthy (nonoperated) postrun knee (►**Table 4**) were compared using paired *t*-test (►**Table 5**).

The paired *t*-test revealed significant differences in number of regions (►**Table 5** and ►**Fig. 6**). In ROI 1 of the knee medial part, significant differences between the pre- and postrun data of operated knee (prerun = 40.72, postrun = 35.73, $p = 0.05$) and between the postrun data of the operated knee versus the healthy knee (operated = 35.73, healthy = 40.21, $p = 0.047$) were documented. A significant difference in medial ROI 4 of the operated knee was also found between the pre- and postrun data (prerun = 33.85, postrun = 30.45, $p = 0.003$; $p = 0.003$). Similar result observed for ROI 5 in the operated knee (prerun = 33.33, postrun = 30.63, $p = 0.007$). Interestingly, the prerun value of the operated knee was significantly higher than that of the healthy knee (operated prerun = 33.33, healthy prerun = 30.93, $p = 0.026$).

Furthermore, significant results were observed in the lateral part of the knee (►**Table 5** and ►**Fig. 7**). The T2 value was significantly lower in the operated knee postrun compared with the healthy knee in ROI 2 (operated = 34.89, healthy = 37.59, $p = 0.043$), ROI 3 (operated = 36.88, healthy = 39.36, $p = 0.017$), ROI 4 (operated = 24.66, heathy = 30.20, $p = 0.009$), and ROI 6 (operated = 28.84, healthy = 33.17, $p = 0.006$). In ROI 6, we also found a significance in the comparison between prerun healthy and prerun operated knee (operated = 30.85, healthy = 34.08, $p = 0.015$). When comparing postrun results of operated knee to its prerun results, it was found that the T2 value was significantly lower in the postrun operated knee compared with the prerun in ROI 2 (postrun = 35.86, prerun = 40.35, $p = 0.015$), ROI 3 (postrun = 34.89, prerun = 37.73, $p = 0.001$), and ROI 4 (postrun = 24.66, prerun = 28.70, $p = 0.0004$).

We did not find any significant results when comparing the postrun healthy knee to the prerun healthy knee in medial or lateral parts of the knees.

A paired *t*-test conducted using the difference of each knee, both in the healthy and operated knees, post- to prerun results were used. A statistical significance in ROI 3 (operated = −3.47, healthy = −0.05, $p = 0.006$) and ROI 4 (operated = −4.04, healthy = 1.15, $p = 0.048$) was noted.

Additionally, multivariate repeated measures analysis of variance (ANOVA) was performed in each knee ROI (►**Table 6**). It revealed a significant difference in the medial side of ROI 5 ($p = 0.041$), ROI 4 ($p = 0.021$), and ROI 6 ($p = 0.004$) of the lateral side.

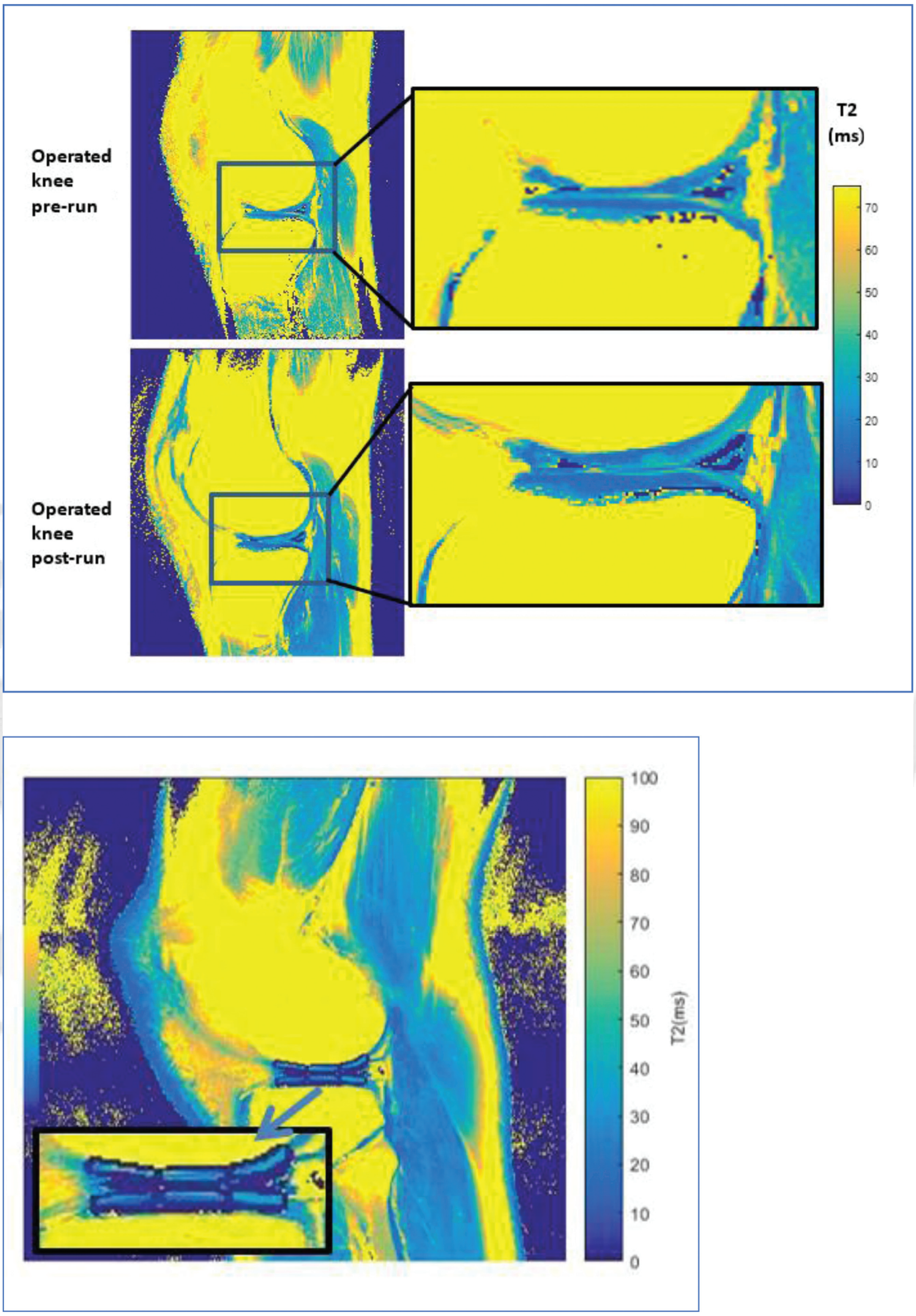

Fig. 2 An example of T2 mapping analysis. An example of the six ROIs in one lateral sagittal slice during analysis of T2 mapping image.

Discussion

Despite all the positive attributes of running, the loading of the joints during running may have a deleterious effect on the joint cartilage of a post–partial meniscectomy knee, leading to osteoarthritis. In the present study, we wanted to examine the effect of running on cartilage of a post–partial meniscectomy knee.

Early-stage OA is clinically silent since the structural changes typically precede clinical signs and symptoms of pain, deformity, functional limitations, and disability.[6] T2 mapping is suggested to be more sensitive in screening cartilage deep tissue matrix structures and changes than the arthroscopic surgery.[18]

Quantitative studies of the static loading effects on cartilage volume, thickness, and water content in tissue

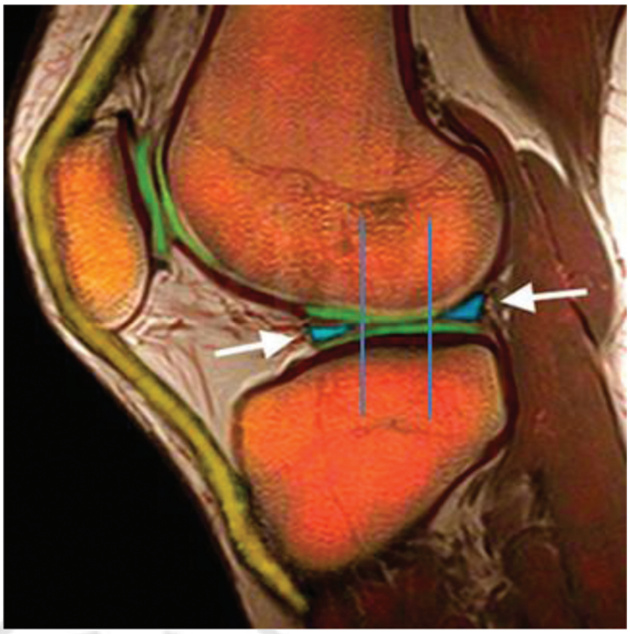

Fig. 3 Superior and inferior surface of the cartilage were each divided into three regions, using the inner margin of the meniscus as a marker for the borders of the weight-bearing regions. This is an example of one of four sagittal sections represented each knee.

specimens (animal and human),[19] intact cadaveric joints, and in vivo human joints have suggested that structural changes in the cartilage matrix occur upon physical activity due to physiologic loading. High-impact sports, such as running, involving repetitive joint loading, have been reported to be a biomechanical risk factor for developing knee osteoarthritis.[14,20] Running disturbs the collagen matrix structure, causing deformation and changes in the orientation of collagen fibers.[11] It also interrupts its composition by expulsion of water molecules within the matrix, resulting in a reduction of the T2 relaxation times.[6]

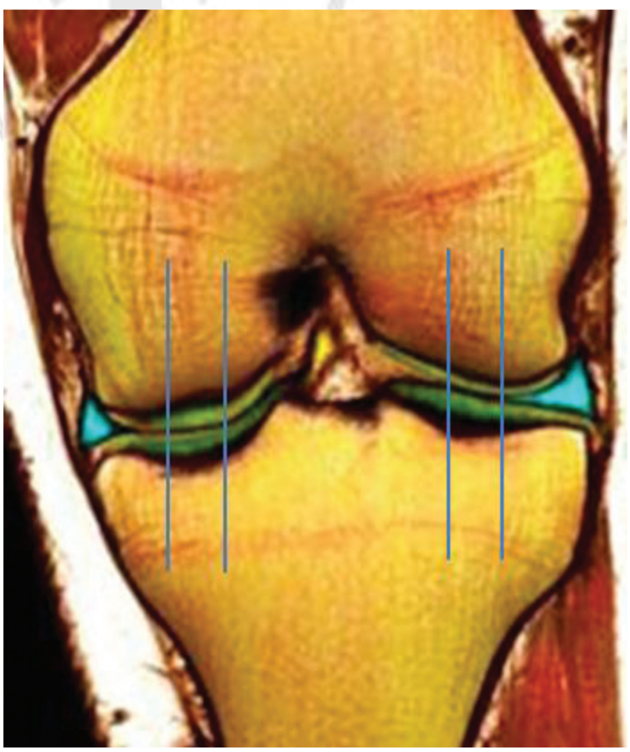

Fig. 4 The four sagittal sections were selected out of 11 available sections, chosen to represent central areas of medial and lateral parts of the knee joint. Two sagittal sections for each compartment. Each section had to be central and to include meniscus area.

Hoessly and Wildi[12] provided an overview of the existing literature on radiological findings in healthy knees of athletes after running. The study suggested a slight and transient quantitative change in hyaline cartilage immediately after running. However, at the longest follow-up of 3 months, no permanent quantitative damage seems to persist.

We hypothesized that the difference (before and after running) in water content in the "damaged" (post–partial meniscectomy) cartilage will be different from the cartilage in the healthy knees. If a difference between healthy and postmeniscectomy knees is observed, this state could presage an early form of osteoarthritic changes. Twelve young healthy volunteers participated in the study. They had undergone medial partial meniscectomy, 1 to 4 years prior to the study. They underwent 3-T MRI of the knee, before and immediately after 30 minutes of running.

In the present study, paired *t*-test revealed significant difference in ROI 1, 4, and 5, in the medial regions of the knees. Overall, the mean value of T2 was lower in the postrun operated knee compared with the same prerun knee, as well as to the postrun healthy knee. The most remarkable difference on the medial side was seen in ROI 1, located at the superior–anterior surface (medial femoral condyle).

As for the lateral regions of the knee, more significant results were seen. The T2 value was significantly lower in the postrun operated knee compared with the same prerun knee, as well as the postrun healthy knee. On lateral side, the most remarkable differences were seen in ROI 3, located at the superior–posterior surface (lateral femoral condyle) and ROI 4, located at the inferior anterior surface (lateral tibial plateau).

These changes can be attributed to a biomechanical alteration as a result of a meniscectomy. We suggest that these regions are more prompt to stress and damage in a post–partial meniscectomy knees during running. No statistical difference was found while comparing postrun healthy knees to prerun healthy knees. In our opinion, the above result (no statistical difference in the healthy knees) contributes to proving the sensitivity and specificity of the study and its other results.

As mentioned, alterations in T2-mapping values could be attributed to the water content change. Higher prerun T2 values in the postmeniscectomy knees than the health knees, could represent a known sign of osteoarthritis, higher water content. Postrun decrease of T2 values in postmeniscectomy knees, compared with healthy knees, can point to another sign of osteoarthritis, the water movement becomes less restricted and more of the compression force is imparted to the collagen and to the aggrecan matrix. However, these changes can be attributed to other unknown causes, other than water content and collagen fibers alteration.

Fig. 5 T2 values for the medial regions of interest—mean value and graphic representation of the standard deviation. ROI, region of interest.

Table 3 T2 values for the ROIs and number of pixels per ROI: pre- and postrun

Prerun						
	Operated knee			Healthy knee		
ROI number[a]	Mean T2 value (ms)	Regions analyzed *n*	Pixels per ROI Mean ± SD	Mean T2 value (ms)	Regions analyzed *n*	Pixels per ROI Mean ± SD
Medial 1						
1	39.33	10	32.10 ± 5.92	41.56	8	28.75 ± 10.01
2	33.87	10	62.10 ± 8.90	38.46	11	56.82 ± 7.65
3	36.43	10	71.90 ± 6.62	37.95	9	57.44 ± 6.48
4	34.81	11	47.45 ± 8.70	33.30	12	39.25 ± 9.54
5	34.07	12	81.75 ± 8.39	30.74	12	86.25 ± 7.81
6	32.66	12	66.67 ± 5.53	32.50	12	69.92 ± 6.93
Medial 2						
1	40.83	12	56.42 ± 8.22	41.44	11	38.27 ± 11.92
2	37.06	12	90.83 ± 6.47	35.10	11	62.64 ± 8.04
3	41.47	12	69.42 ± 7.06	38.82	11	62.64 ± 5.40
4	33.64	12	39.08 ± 8.03	29.96	12	35.67 ± 6.76
5	33.40	12	100.25 ± 7.86	31.78	12	85.67 ± 7.43
6	34.56	12	66.00 ± 5.82	32.36	12	66.17 ± 5.73
Lateral 1						
1	38.47	5	27.00 ± 10.90	33.90	4	29.75 ± 6.96
2	37.86	12	60.75 ± 7.72	38.78	12	57.83 ± 6.88
3	39.96	12	70.25 ± 4.60	40.35	11	73.73 ± 5.69
4	28.33	12	50.17 ± 7.20	28.71	12	48.58 ± 9.93
5	26.44	12	109.00 ± 5.55	28.15	12	104.33 ± 7.61

(*Continued*)

Table 3 (*Continued*)

6	30.69	12	72.75 ± 6.14	33.75	12	74.33 ± 6.85
Lateral 2						
1	40.59	9	33.78 ± 7.44	38.91	11	44.09 ± 14.48
2	37.41	12	61.33 ± 6.60	36.75	12	74.67 ± 7.67
3	40.84	12	74.33 ± 4.80	39.00	11	86.36 ± 5.35
4	29.24	12	47.92 ± 6.43	29.60	12	46.25 ± 8.85
5	29.31	12	80.42 ± 6.02	30.81	12	103.08 ± 7.93
6	31.66	12	65.17 ± 5.33	34.54	12	89.75 ± 7.33
Postrun						
	Operated knee			**Healthy knee**		
ROI number	**Mean T2 value (ms)**	**Regions analyzed *n***	**Pixels per ROI Mean ± SD**	**Mean T2 value (ms)**	**Regions analyzed *n***	**Pixels per ROI Mean ± SD**
Medial 1						
1	34.75	10	32.80 ± 7.59	45.47	5	33.00 ± 6.05
2	35.04	10	60.40 ± 9.29	34.47	9	61.44 ± 7.37
3	34.83	8	58.00 ± 6.29	36.68	8	47.88 ± 5.29
4	31.01	12	36.42 ± 5.40	32.31	12	35.67 ± 6.96
5	30.68	12	90.50 ± 6.07	30.34	12	99.58 ± 6.26
6	31.48	12	66.75 ± 5.41	31.15	12	65.42 ± 5.40
Medial 2						
1	35.40	12	44.75 ± 6.00	39.55	10	43.00 ± 8.28
2	33.43	12	79.92 ± 6.50	37.26	10	69.20 ± 10.06
3	37.87	12	68.50 ± 7.51	35.46	10	70.60 ± 6.11
4	30.11	11	41.91 ± 6.81	29.07	12	40.50 ± 6.54
5	32.04	12	86.83 ± 6.75	31.21	12	87.50 ± 6.88
6	32.07	12	70.17 ± 6.84	30.17	12	73.50 ± 5.53
Lateral 1						
1	36.57	6	25.17 ± 6.50	32.11	7	23.29 ± 8.07
2	35.43	12	76.33 ± 8.19	38.00	12	48.50 ± 6.89
3	37.22	12	71.25 ± 5.27	41.05	12	84.42 ± 5.52
4	24.03	12	48.25 ± 6.41	31.34	12	47.75 ± 8.00
5	25.24	12	130.67 ± 5.74	28.25	12	105.58 ± 6.64
6	28.20	12	72.08 ± 5.58	32.24	12	78.42 ± 6.32
Lateral 2						
1	35.51	10	38.00 ± 8.92	37.29	12	36.42 ± 11.87
2	34.93	11	67.36 ± 5.12	37.17	12	77.75 ± 7.46
3	36.72	12	73.42 ± 4.88	38.03	12	77.17 ± 4.32
4	25.13	12	47.00 ± 5.55	29.24	12	54.00 ± 7.90
5	29.49	12	106.00 ± 6.47	30.25	12	106.92 ± 6.93
6	29.52	12	58.08 ± 4.47	34.02	12	76.58 ± 6.73

Abbreviations: ROI, region of interest; SD, standard deviation.
[a]The location of each ROI was as follows: 1, anterior femur; 2, central femur; 3, posterior femur; 4, anterior tibia; 5, central tibia; 6, posterior tibia.

Table 4 Mean combined T2 values in each ROI

ROI number	Prerun		Post-run	
	Operated knee	Healthy knee	Operated knee	Healthy knee
Medial combined				
1	40.72	42.44	35.73	40.21
2	36.26	38.32	34.75	36.95
3	39.31	38.71	37.17	35.71
4	33.85	31.39	30.45	30.79
5	33.33	30.93	30.63	30.44
6	33.56	31.84	31.21	30.55
Lateral combined				
1	40.35	38.37	35.86	35.75
2	37.73	37.59	34.89	37.59
3	40.35	39.41	36.88	39.36
4	28.70	29.05	24.66	30.20
5	27.47	28.83	27.09	28.96
6	30.85	34.08	28.84	33.17

Abbreviation: ROI, region of interest.
Note: Mean combined = ([mean value 1 × mean pixels 1] + [mean value 2 × mean pixels 2]) / (mean pixels 1 + mean pixels 2).

In this study, changes of the articular cartilage in the medial and lateral compartments of the knees were found in the post–partial meniscectomy knees. Changes in post–partial meniscectomy knees after running, compared with a healthy knee, revealed that running might had a negative impact on an articular cartilage of postmeniscectomy knees. This suggests that post–partial meniscectomy knees articular cartilage may be more prompt to stress and damage during running, in all regions of these knees. Whether this damage is transient, and whether we should advise our patients to refrain from running after partial meniscectomy, should be further investigated in long-term studies.

Limitations

Our study has several limitations, one being the low number of participants. Moreover, the patients' physical strength was very variable. There is a 4-year time period during which the

Table 5 Paired *t*-test results for the ROI analysis (*p*-values)

ROI number	Operated vs. healthy		Postrun vs. prerun		ΔPostrun to prerun of operated vs. healthy
	Prerun	Postrun	Healthy	Operated	
Medial					
1	0.751	**0.047**	0.510	**0.050**	0.502
2	0.245	0.149	0.693	0.483	0.749
3	0.828	0.727	0.068	0.218	0.803
4	0.216	0.762	0.687	**0.003**	0.169
5	**0.026**	0.813	0.483	**0.007**	0.053
6	0.302	0.667	0.124	0.078	0.418
Lateral					
1	0.970	0.893	0.499	0.261	0.856
2	0.925	**0.043**	0.996	**0.015**	0.132
3	0.160	**0.017**	0.851	**0.001**	**0.006**
4	0.849	**0.009**	0.603	**0.0004**	**0.048**
5	0.301	0.196	0.923	0.691	0.638
6	**0.015**	**0.006**	0.579	0.160	0.532

Abbreviation: ROI, region of interest.
Note: Bolded *p*-values indicate statistically significant differences ($p < 0.05$).

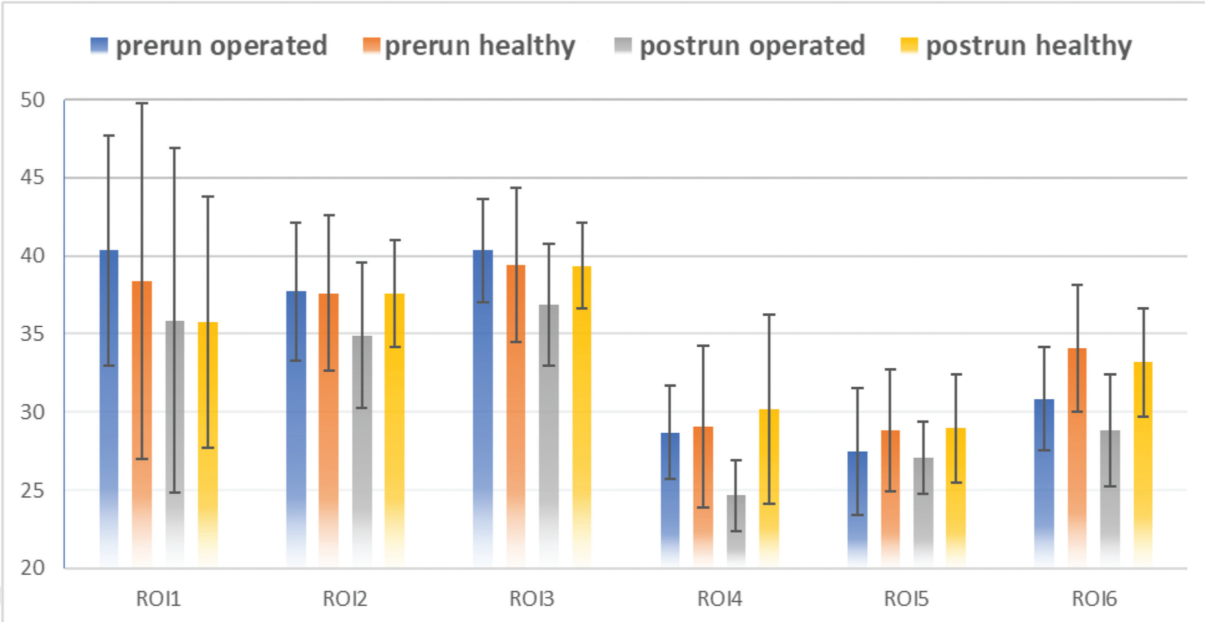

Fig. 6 T2 values for the lateral regions of interest—mean value and graphic representation of the standard deviation. ROI, region of interest.

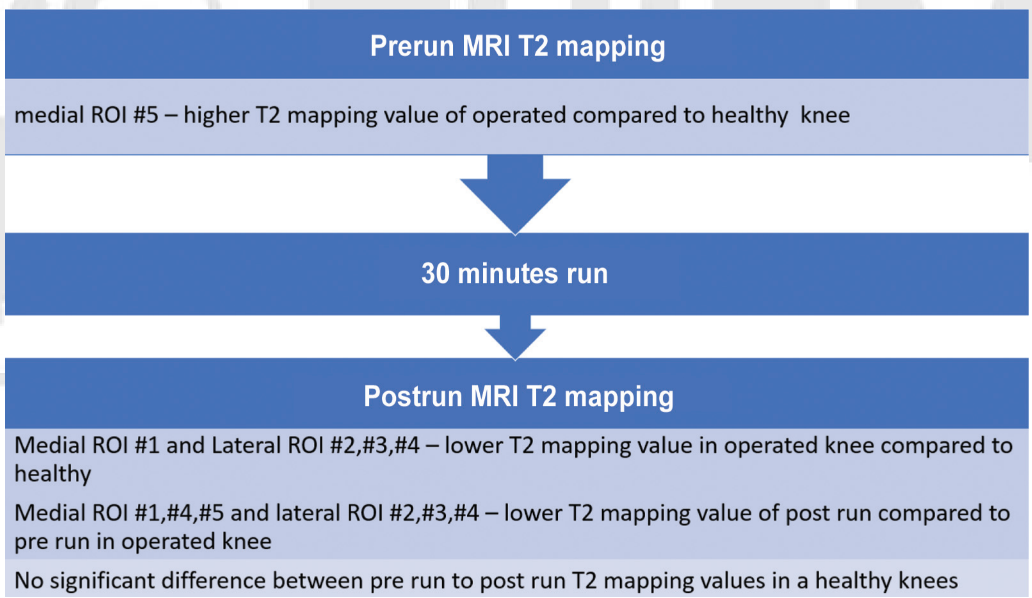

Fig. 7 Results—summary. MRI, magnetic resonance imaging; ROI, region of interest.

patients would have received a partial meniscectomy, However, it is conceivable that patients who were treated earlier on in this window may have developed early onset OA as a result and are a different subset compared with those later in this window. We included patients who underwent a medial meniscectomy without significant cartilage damage, but this was only an estimate during the surgery. We do not have a reliable information about exact size of the meniscus which was extracted. Our results represent an acute change in the articular cartilage at one single point of time (immediately after running).

Conclusion

Lower T2 values were found in post–partial meniscectomy knees after 30 minutes of running. These changes were seen in both the medial and lateral compartments. These changes may represent an early form of osteoarthritic changes. We suspect that running may subject the articular cartilage to excessive loads in the post–partial meniscectomy knee, loads that in healthy knee do not cause any changes. Thus, an aerobic exercise with less stress impact (such as swimming and cycling) might be advised even after a partial

Table 6 ANOVA: single-factor analysis of each ROI

ROI number	*p*-Value between groups
Medial	
1	0.440
2	0.316
3	0.540
4	0.153
5	**0.041**
6	0.276
Lateral	
1	0.697
2	0.333
3	0.180
4	**0.021**
5	0.461
6	**0.004**

Abbreviations: ANOVA, analysis of variance; ROI, region of interest.
Note: Bolded *p*-values indicate statistically significant differences ($p < 0.05$).

meniscectomy. However, further long-term investigations involving more participants are required to achieve conclusive results.

Conflict of Interest
None declared.

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