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FULL PAPER

Longitudinal study of the morphological and T2* changes of knee cartilages of marathon runners using prototype software for automatic cartilage segmentation

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Objective: To study the effect of long-distance running on the morphological and T2* assessment of knee cartilage.
Methods: 3D-DESS and T2* mapping was performed in 12 amateur marathon runners (age: between 21 and 37 years) without obvious morphological cartilage damage. MRI was performed three times: within 24 h before the marathon, within 12 h after the marathon, and after a period of convalescence of two months. An automatic cartilage segmentation method was used to quantitatively assessed the morphological and T2* of knee cartilage pre- and post-marathon. The cartilage thickness, volume, and T2* values of 21 sub-regions were quantitatively assessed, respectively.
Results: The femoral lateral central (FLC) cartilage thickness was increased when 12-h post-marathon compared with pre-marathon. The tibial medial anterior (TMA) cartilage thickness was decreased when 2 months post-marathon compared with pre-marathon. The tibial lateral posterior (TLP) cartilage volume was increased when 12-h post-marathon compared with pre-marathon. The cartilage T2* value in most sub-regions had the upward trend when 12-h post-marathon and restored trend when 2 months post-marathon, compared with pre-marathon. The femoral lateral anterior (FLA) and TMA cartilage volumes were decreased 2 months post-marathon compared with pre-marathon.
Conclusions: The marathon had some effects on the thickness, volume, and T2* value of the knee cartilages. The thickness and volume of knee cartilage in most sub-regions were without significantly changes post-marathon compared with pre-marathon. T2* value of knee cartilage in most sub-regions was increased right after marathon and recovered 2 months later. The TLP and TMA subregions needed follow-up after marathon.
Advances in knowledge: The morphological and T2* changes of knee cartilage after marathon were evaluated by MRI and automatic segmentation software. This study was the first to use cartilage automatic segmentation software to evaluate the effects of marathon on the morphology and biochemical components of articular cartilage, and to predict the most vulnerable articular cartilage subregions, for the convenience of future exercise adjustment and the avoidance of sports cartilage injury.

INTRODUCTION

The marathon has been widely used as a model of investigating the limits of physiology function. In 2018, the number of participants of marathon reached million.[1] It is expected that the number of participants in 2020 will exceed 10 million. The continuous development and popularization of marathon sports has also brought some negative impacts while improving people's physical fitness. For amateur marathon runners, they are more susceptible to damage to the musculoskeletal system due to lack of professional running knowledge and guidance than professional athlete. In longer ultra-marathons, 50–60% of the participants experience musculoskeletal problems.[2] The early assessment of injuries for amateur marathon runners has become a hot topic of recent research and discussion.[3,4]

In marathon, the incidence of lower extremity running injuries is high due to repeated and huge loads acting on the lower extremity joints for a long time. The knee is the most frequently injured joint in runners.[5] Common knee

joint injuries include cartilage injury, sacroiliac tibial syndrome, patella pain syndrome, meniscus injury, bone marrow edema, patellar tendinitis, and ligament injury.[6,7] Articular cartilage injury is one of the hot topics of research and discussion in recent years. Studies have shown that during a marathon, the average vertical force on the knee joint of a 70 KG athlete is 2800N, and articular cartilage plays an important role in the process of stress transmission to the sub-articular bone.[8] As a biological shock absorber, articular cartilage can absorb and buffer stress to the greatest extent, and at the same time, it evenly transmits the force to the bone below the joint to avoid joint damage. However, articular cartilage is not easy to recover after injury. Many studies have shown that long-term load can cause degenerative changes of cartilage, leading to the occurrence of osteoarthritis.[9–11]

MRI was widely used to evaluate the morphological changes of knee joints before and after exercise, such as meniscus injury, joint effusion, bone marrow edema, peri-articular cysts, and ligament integrity changes.[12–14] 3-D US can evaluate the morphology of cartilage, and its measurements are reproducible and correlate strongly with MRI measurements.[15] However, there are relatively few studies on knee ultrasound evaluating the cartilage, and its feasibility needs to be further verified. Those were morphological changes of the knee joint.

So far, MRI is the non-invasive and effective examination method that can observe and quantitatively evaluate joint cartilage *in vivo*. With the development of technology, a large number of quantitative MRI techniques have emerged in recent years, including T2-mapping, T2*-mapping, spin lattice relaxation in rotating frames (T1rho), and magnetic resonance delayed enhanced cartilage imaging (dGEMRIC), GAG chemical exchange saturation transfer imaging (MR gagCEST), et al. Among them, T2-mapping, T2*-mapping, and T1rho have been used in knee joint cartilage studies.[12,16] The change in T2* value reflects a comprehensive change in lateral relaxation time and magnetic field heterogeneity, and is sensitive to the anisotropy of collagen fibers and moisture in articular cartilage.[16] Therefore, this method is often used to study the changes in the composition of early chondrocyte matrix. In this study, T2 * mapping and high-resolution 3D MRI were used to assess the short-term and relatively long-term changes of knee cartilage in marathon runners.

METHODS AND MATERIALS

We recruited 12 amateur marathon runners (five males and seven females) for this study, who run marathons less than two times. The participants were between 21 and 37 years old and had a range of body mass index (BMI) of 17.6–27.2 kg m^{-2}. Inclusion criteria were (1) age between 18 and 40 years old; (2) the BMI <28 kg m^{-2}; (3) no history of knee joint trauma, surgery, or infections; (4) no history of chronic diseases requiring long-term drug therapy; and (5) no history of vigorous exercise after the marathon. The exclusion criteria were: (1) knee joint trauma occurring during the study period; (2) pre-marathon images showing morphological injury of the articular cartilage; (3) knee joint pain or other positive sign; and (4) MRI contraindications.

Magnetic resonance imaging protocols

MRI was performed on both knee joints of all subjects within 24 h before marathon, within 12 h after marathon, and after a period of convalescence of 2 months using a 3T MR scanner (MAGNETOM Verio, Siemens Healthcare, Erlangen, Germany), with a dedicated 8-channel knee coil. High-resolution morphological 3D knee images were obtained using a 3D-DESS sequence with selective water excitation. The imaging parameters were as following: voxel size 0.7 × 0.6 × 0.7 mm^3, TR 14.45 ms, TE 5.17 ms, flip angle 25°, FOV: 160 × 160 mm^2, slice thickness 0.68 mm, matrix: 256 × 256 × 240. Sagittal T2* maps were obtained using a gradient echo sequence, utilizing five echoes for the fit: TR = 1340 ms, TE = 4.36, 11.9, 19.44, 26.98, 34.52 ms, FOV = 160.0 × 160.0 mm^2, matrix = 384 × 384, flip angle = 60°, slice thickness = 3.0 mm. All subjects rested for 1 h before the MRI examination and were examined supine with the lower edge of the patella as the scanning center, minimizing motion artifacts by using sandbags and sponges.

Cartilage segmentation

Knee cartilage was automatically segmented to 21 subregions using post-processing prototype software (Siemens Chondral Health, version 2.1, Siemens Healthcare, Erlangen, Germany). This software automatically divides the knee cartilage into three parts—femoral, patellar and tibia cartilage—consisting of 21 cartilage regions (listed in Table 1 and Figure 1). Cartilage volume, thickness and T2* relaxation time were acquired by automatic segmentation, respectively. Upon completion of automatic segmentation, manual adjustment was applied to avoid joint effusion and cartilage morphology resulting in automatic identification misalignment. Image analysis done by both observers with inter-observer agreement.

Statistical analysis

Statistical analysis was done by the SPSS v.17.0 (Chicago, IL) and was expressed as mean ± standard deviation. $p < 0.05$ indicated that the difference was statistically significant. The paired rank sum test and Friedman M test were used to compare the volume, thickness and T2* relaxation parameter of cartilage and the rate of change in each parameter in the different regions.

RESULTS

Thickness changes of subregions

The cartilage thicknesses of these subregions of FTM ($X^2 = 7.75$, $p < 0.05$), FTL ($X^2 = 7.14$, $p < 0.05$), TLP ($X^2 = 8.87$, $p < 0.05$), and TMA ($X^2 = 5.87$, $p < 0.05$) were negative significant differences, and the cartilage thickness of FLC subregion ($X^2 = 7.47$, $p < 0.05$) (Table 2) was positive significant difference. Post-hoc test showed that the cartilage thickness of the FLC subregion was increased at 12 h post-marathon ($p < 0.05$; Figure 2), and the thickness of the TMA subregion was decreased at 2 months post-marathon ($p < 0.05$; Figure 2).

Volume changes of subregions

The cartilage volumes of these subregions of FLC ($X^2 = 12.25$, $p < 0.05$), FLA ($X^2 = 6.28$, $p < 0.05$), TLP ($X^2 = 8.97$, $p < 0.05$), and TMA ($X^2 = 9.74$, $p < 0.05$) were negative significant differences (Table 3). Post-hoc test showed that the cartilage volume of the

Table 1. The 21 cartilage regions of knee were automatically divided by the software

Three parts	Femoral cartilage	Patellar cartilage	Tibia cartilage
Subregions	FMP	PLI	TLP
	FMC	PLC	TLC
	FMA	PLS	TLA
	FTM	PMI	TMP
	FTC	PMC	TMC
	FTL	PMS	TMA
	FLP		
	FLC		
	FLA		

FLA, Femoral lateral anterior; FLC, Femoral lateral central; FLP, Femoral lateral posterior; FMA, Femoral medial anterior; FMC, Femoral medial central; FMP, Femoral medial posterior; FTC, Femoral trochlea central; FTL, Femoral trochlea lateral; FTM, Femoral trochlea medial; PLC, Patellar lateral central; PLI, Patellar lateral inferior; PLS, Patellar lateral superior; PMC, Patellar medial central; PMI, Patellar medial inferior; PMS, Patellar medial superior; TLA, Tibial lateral anterior; TLC, Tibial lateral central; TLP, Tibial lateral posterior; TMA, Tibial medial anterior; TMC, Tibial medial central; TMP, Tibial medial posterior.

TLP subregion was increased at 12-h post-marathon ($p < 0.05$; Figure 3), and the volumes of the FLA and TMA subregions were decreased at 2 months post-marathon ($p < 0.05$; Figure 3).

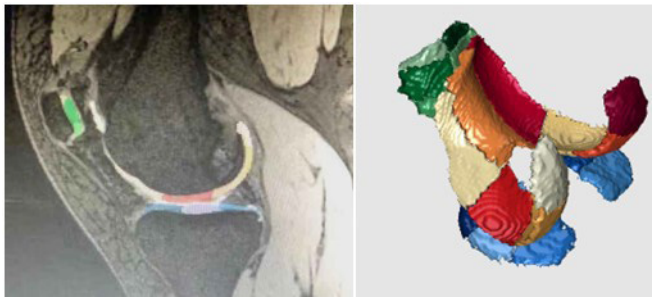
T2* value changes of subregions

The cartilage T2* values of these subregions of FMC ($X^2 = 7.75$, $p < 0.05$), FTM ($X^2 = 9.25$, $p < 0.05$), FLP ($X^2 = 9.25$, $p < 0.05$), PMC ($X^2 = 7.00$, $p < 0.05$), and PMS ($X^2 = 6.25$, $p < 0.05$) were positive significant differences, and the cartilage T2* value of TMA subregion ($X^2 = 7.00$, $p < 0.05$) was negative difference (Table 4). Post-hoc test showed that the cartilage T2* values of these subregions of FMC, FMA, FLP, FLC, FLA, PLC, PMI, and PMC were increased at 12-h post-marathon, and the cartilage T2* value of TMC subregion was decreased at 12-h post-marathon ($p < 0.05$; Figure 4). The cartilage T2* values of these subregions of FMC, FTM, and FLP were increased at 2 months post-marathon, and the cartilage T2* value of TMA subregion was decreased at 2 months post-marathon ($p < 0.05$; Figure 4).

DISCUSSION

Regarding the change of cartilage volume after long-distance running, scholars hold different views. Some scholars claimed that the mechanical load caused by long-distance running will not cause internal pressure on bone and cartilage because the developed anatomy of the knee joint, which prevents the cartilage volume from changing.[8] On the contrary, Kessler founded that the cartilage volume of the patella and tibia were reduced by 7.0 and 5.1% after running 20 km, respectively. After 1 h rest, the cartilage volume is recovered.[17]

Figure 1. The sub-regions of knee cartilage automatically segmented by software with different colors. The green ones are patellar cartilage, the warm ones are femoral cartilage, and the blue ones are tibial cartilage.



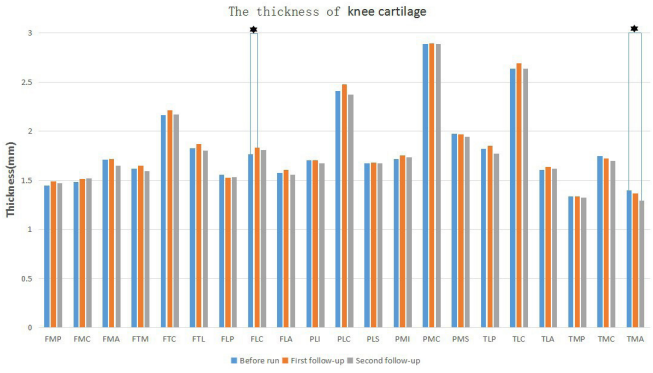
The above studies explored the short-term effects of running on cartilage deformation. In this study, the observation time windows were placed at before, 12 h after and 2 months after marathon. The results showed that the most sub-regions of cartilage without significant differences of volume and thickness among three MRI examinations. The significant differences were seen in FLC, TLP and TMA sub-regions both volume and thickness among three MRI examinations. We believed that the cartilage volume and thickness have changed to a certain extent after running. It can be inferred from this study, among the effects of marathon on cartilage morphology, the change of cartilage thickness was more sensitive than the change of cartilage volume in the evaluation of the impact of short time, because the subregions of cartilage thickness changes overlapped more with the subregions of cartilage T2* changes. However, in the evaluation of the effect of relatively long-time, the change of cartilage volume was more specific, and the effect of exercise on the subregion was more persistent where the cartilage volume was significantly reduced. After a recovery period of one hour, it was found that the reduction rate of cartilage volume was smaller than before, and it was no longer statistically significant, which is consistent with our research results.[17] A study was focused on the short-term effects of marathon exercise on cartilage volume and thickness, and found that the volume and thickness of lateral femur cartilage decreased by a mean of 3.2 ± 3.0 and 1.7 ± 1.6%, respectively. No significant changes in cartilage volume and thickness were observed at other regions.[4] The reduction of cartilage volume post marathon required a certain amount of time to recover, while the specific time for the cartilage volume to recover pre-marathon level after marathon remains to be studied and discussed.

Table 2. The thicknesses of 21 sub-regions of knee cartilage

Sub regions	Pre-run	12-h post-run	2 months post-run	X^2	*p* value
FMP	1.4460 ± 0.2165	1.4358 ± 0.1678	1.4470 ± 0.2003	1.000	0.607
FMC	1.4710 ± 0.16441	1.4608 ± 0.1718	1.4690 ± 0.2010	1.000	0.607
FMA	1.6960 ± 1.5196	1.6750 ± 0.1405	1.6050 ± 0.1697	1.750	0.417
FTM	1.6190 ± 0.1660	1.6133 ± 0.1601	1.5750 ± 0.1345	7.750	0.021
FTC	2.1540 ± 0.3617	2.1550 ± 0.3443	2.1290 ± 0.3388	2.480	0.289
FTL	1.8240 ± 0.2388	1.8408 ± 0.2242	1.7760 ± 0.2034	7.143	0.028
FLP	1.5490 ± 0.1460	1.5017 ± 0.1753	1.5000 ± 0.1425	1.724	0.422
FLC	1.7430 ± 0.2827	1.7783 ± 0.2837	1.7750 ± 0.2762	7.467	0.024
FLA	1.5620 ± 0.2480	1.5950 ± 0.2423	1.5640 ± 0.2457	4.323	0.115
PLI	1.6870 ± 0.3528	1.6958 ± 0.3175	1.6460 ± 0.2032	0.452	0.798
PLC	2.4290 ± 0.3801	2.4792 ± 0.3512	2.3810 ± 0.2666	3.250	0.197
PLS	1.7120 ± 0.3051	1.6867 ± 0.2265	1.7070 ± 0.2261	2.516	0.284
PMI	1.6920 ± 0.2138	1.7467 ± 0.1974	1.7730 ± 0.2155	0.452	0.798
PMC	2.8880 ± 0.3782	2.8800 ± 0.3235	2.9080 ± 0.2880	1.000	0.607
PMS	2.0230 ± 0.3629	1.9925 ± 0.2160	1.9300 ± 0.2385	0.250	0.882
TLP	1.8270 ± 0.3782	1.8708 ± 0.3168	1.8220 ± 0.2811	8.867	0.012
TLC	2.6370 ± 0.3935	2.6733 ± 0.3549	2.6490 ± 0.2901	4.323	0.115
TLA	1.6550 ± 0.2309	1.7033 ± 0.2573	1.6280 ± 0.1794	1.742	0.419
TMP	1.3670 ± 0.1430	1.3458 ± 0.1250	1.3210 ± 0.1187	2.000	0.368
TMC	1.7830 ± 0.1843	1.7458 ± 0.1908	1.6810 ± 0.1741	0.194	0.908
TMA	1.4090 ± 0.1543	1.3875 ± 0.1409	1.2790 ± 0.1534	5.871	0.053

In recent years, many scholars have used T2 mapping or T2 * mapping methods to explore the changes of cartilage during marathon, and the results obtained are not the same. T2-mapping technology is a multi-level multi-echo spin echo sequence. The T2 value is mainly affected by the water content in the cartilage and the fluidity of the water. The increase of T2 value often represents an increase in water content and loss of anisotropy of collagen fibers.[3] Similar to T2-mapping, T2*-mapping is sensitive to the extracellular water content and the interaction between water molecules and collagen fibers. The high T2* value reflects high water content and mobility. The difference is that T2 mapping imaging is generally a spin echo sequence, and the image is susceptible to magnetic field inhomogeneity, while T2* mapping uses a multi echo gradient sequence, which has fast imaging speed, feasible three-dimensional acquisition, high spatial resolution, and comprehensive articular surface coverage.[15]

Figure 2. The thickness changes of each cartilage subregion in three times of MRI, asterisks indicate statistically significant difference.



In this study, T2* map was used to evaluate the changes of biochemical composition of knee joint cartilage before and after the marathon. The results showed that T2* values of femoral cartilage, medial tibial cartilage, and medial patella area were significantly increased, except for the femoral trochlear. It was consistent with the results of Hesper's.[16] This was mainly related to the partial loss of glycosaminoglycan (GAG) in cartilage, which weakened the restriction of macromolecular substances on the mobility of free water, and the increased mobility of water lead to an increase of T2 * relaxation time. In addition, the high intensity of repeated loads made the skeletal collagen fiber changes resulting in the partial loss of anisotropy of collagen fibers. That was also an important factor for the increase of T2* relaxation time.

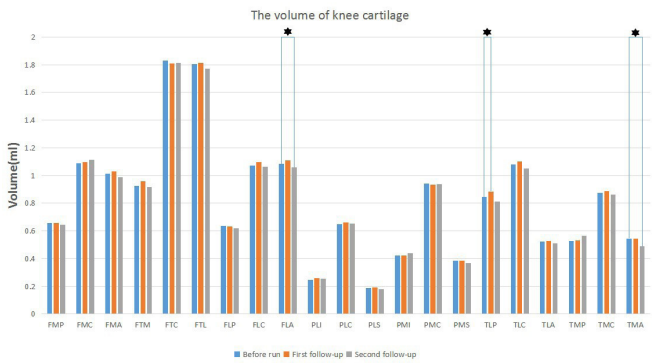
There were some studies inconsistent with the results of this study. In the Mosher's study, the T2 relaxation time of the superficial

Table 3. The volumes of 21 sub-regions of knee cartilage

Sub regions	Pre-run	12-h post-run	2 months post-run	X^2	*p*-value
FMP	0.6540 ± 0.1903	0.6283 ± 0.1358	0.6250 ± 0.1776	0.452	0.798
FMC	1.0750 ± 0.2431	1.0592 ± 0.1924	1.0810 ± 0.2392	0.839	0.657
FMA	0.9920 ± 0.1854	0.9692 ± 0.1768	0.9380 ± 0.1966	4.323	0.115
FTM	0.9170 ± 0.1889	0.9008 ± 0.1924	0.8780 ± 0.1614	5.250	0.072
FTC	1.7900 ± 0.4130	1.6900 ± 0.4274	1.7250 ± 0.3806	1.724	0.422
FTL	1.7710 ± 0.3767	1.7233 ± 0.3332	1.7080 ± 0.2971	4.710	0.095
FLP	0.6480 ± 0.1327	0.6333 ± 0.1328	0.6160 ± 0.1225	0.065	0.968
FLC	1.0550 ± 0.2309	1.0708 ± 0.2279	1.0600 ± 0.2184	12.250	0.002
FLA	1.0500 ± 0.2595	1.0533 ± 0.2666	1.0300 ± 0.2338	6.276	0.043
PLI	0.2440 ± 0.0698	0.2583 ± 0.0798	0.2500 ± 0.0572	1.462	0.482
PLC	0.6650 ± 0.1523	0.6442 ± 0.1664	0.6250 ± 0.1144	0.600	0.741
PLS	0.2050 ± 0.0871	0.1908 ± 0.0601	0.1750 ± 0.0344	1.750	0.417
PMI	0.4080 ± 0.1171	0.4242 ± 0.1084	0.4290 ± 0.1280	0.621	0.733
PMC	0.9360 ± 0.1702	0.9092 ± 0.1628	0.8990 ± 0.1678	0.581	0.748
PMS	0.4090 ± 0.1484	0.3925 ± 0.1017	0.3620 ± 0.0636	0.897	0.639
TLP	0.8580 ± 0.2754	0.8533 ± 0.2191	0.8060 ± 0.1970	8.968	0.011
TLC	1.0660 ± 0.2599	1.0433 ± 0.2338	1.0260 ± 0.2227	5.871	0.053
TLA	0.5350 ± 0.1681	0.5317 ± 0.1607	0.4960 ± 0.1405	0.452	0.798
TMP	0.5210 ± 0.0690	0.5042 ± 0.0948	0.5370 ± 0.1089	3.935	0.14
TMC	0.8550 ± 0.1702	0.8375 ± 0.1677	0.8190 ± 0.1856	3.071	0.215
TMA	0.5480 ± 0.1364	0.5325 ± 0.1280	0.4780 ± 0.1195	9.742	0.008

cartilage of the femur and tibia was decreased after the participants finished 30 min (approximately 5000 m) run.[18] It was focus on the superficial cartilage of knee joint, while, this study was focus on the full layer of articular cartilage. Another aspect, there may be some relationship between the T2 or T2* relaxation time changes with the running distance and load bearing time. After short distance running, such as a half marathon, the values of T2 and T2 * maybe tend to decrease after running. The possible reason is that the fluid in the superficial cartilage transfer to the deep side with load bearing; after long distance running, T2 and T2 * values maybe tend to increase, such as full marathon, super marathon, due to partial degradation of proteoglycan in cartilage and changes in skeletal collagen fiber, resulting in partial loss of anisotropy of collagen fiber. Luke studied the changes of T2 value in the cartilage of the knee joint after the full marathon. The results showed that the T2 value of cartilage increased significantly within 48 h after running, which is the same as this study.

Figure 3. The volume changes of each cartilage subregion in three times of MRI, asterisks indicate statistically significant difference.



We found that the areas where the force concentrated have significant differences of T2* values after marathon compared with pre-marathon. The number of cartilage subregions of T2* value changed post-marathon was significantly higher than that of morphological changed. It indicated that T2* value was more sensitive to the biochemical and structural changes of cartilage than morphology. The T2* values of the femoral trochlear did not change significantly, while the T2* values of the medial cartilage area of the femur, tibia, and patella were obviously increase. It may be due to the large contact area of the medial tibiofemoral platform cartilage of the knee joint during exercise, and the stress will also act on the patellar platform cartilage. What's more, the 60–80% of the knee pressure load is transmitted through the medial cartilage.

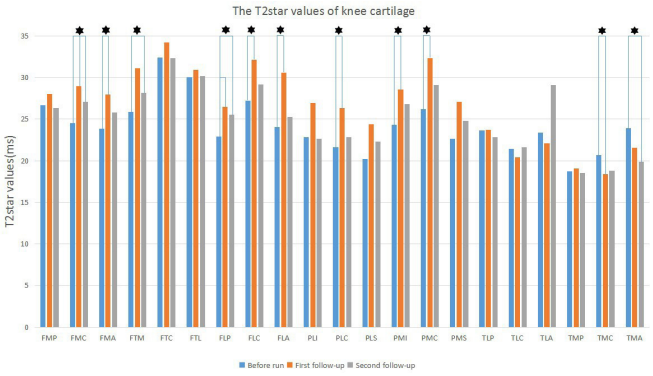
After comparing the T2* value changes between the pre-marathon and the 2 month recovery period, the T2* values of most areas were close to the pre-marathon level after a period

Table 4. The T2* values of 21 sub-regions of knee cartilage

Sub regions	Pre-run	12 h post-run	2 months post-run	X^2	*p* value
FMP	26.8140 ± 2.9093	26.8117 ± 2.6064	26.0570 ± 3.5588	0.750	0.687
FMC	24.7960 ± 3.3544	28.2042 ± 3.9048	26.4010 ± 3.0143	7.750	0.021
FMA	23.7490 ± 3.4570	27.2967 ± 2.8618	24.7370 ± 4.8945	5.250	0.072
FTM	26.0240 ± 3.2980	29.5058 ± 7.0735	27.5550 ± 4.1877	9.250	0.01
FTC	31.7720 ± 5.7471	32.6842 ± 8.3347	31.3410 ± 5.2931	1.000	0.607
FTL	29.5850 ± 3.0265	29.8358 ± 4.4919	29.7330 ± 2.3493	0.250	0.882
FLP	23.4380 ± 2.8626	25.7108 ± 2.5188	25.0240 ± 3.0547	9.250	0.01
FLC	27.0000 ± 2.7988	30.3275 ± 4.7437	28.2640 ± 3.6302	5.250	0.072
FLA	24.5220 ± 6.3202	29.3975 ± 5.3554	25.2360 ± 3.8326	4.000	0.135
PLI	22.5560 ± 5.3755	25.3042 ± 4.7913	23.4290 ± 5.6574	2.250	0.325
PLC	22.4950 ± 5.5133	25.6225 ± 3.2824	23.4570 ± 3.7510	4.750	0.093
PLS	21.9810 ± 6.3075	24.1075 ± 2.6461	22.9980 ± 2.7201	4.750	0.093
PMI	25.1500 ± 2.8294	28.7158 ± 3.3098	27.4580 ± 6.7601	4.000	0.135
PMC	27.7510 ± 4.2947	31.7875 ± 3.0928	30.5200 ± 6.6304	7.000	0.03
PMS	23.8790 ± 4.3198	26.2150 ± 3.6092	26.3940 ± 6.3590	6.250	0.044
TLP	23.7470 ± 3.0178	23.0267 ± 2.5010	22.5250 ± 2.0028	2.250	0.325
TLC	21.1280 ± 3.0559	20.1642 ± 2.4046	21.1280 ± 3.5948	1.000	0.607
TLA	22.8000 ± 4.7100	22.5425 ± 2.8664	27.9630 ± 8.7169	2.250	0.325
TMP	18.8930 ± 2.5052	18.5575 ± 2.6489	18.4490 ± 1.9549	3.250	0.197
TMC	20.4810 ± 3.2483	17.9325 ± 1.7727	18.3240 ± 2.8053	5.250	0.072
TMA	23.7690 ± 5.6100	20.9917 ± 4.0921	20.9830 ± 6.2824	7.000	0.03

of recovery, indicating that with the decrease of activity, the changes of the biochemical components would be eventually recovered. It was suggested that long-distance running would not cause continuous fluid changes. However, the T2* values of the medial femoral medial and lateral femoral posterior cartilage were still significantly different from pro-marathoon level after the recovery period, and further follow-up observation was essential.

Figure 4. The T2* values changes of each cartilage subregion in three times of MRI, asterisks indicate statistically significant difference.



After marathon, the cartilage thickness and volume were both changed in TLP and TMA subregions, and the TMA subregion also showed significant T2* changes. The results indicated that these two subregions were the high-frequency injury sites of knee joint post-marathon, and the changes of these two subregions should be followed up after marathon, so as to find the signs of sports injury early, to adjust the exercise intensity in time, and to avoid irreversible cartilage injury.

Limitations

This current study had several limitations. First, this study observed the changes of knee joint cartilage of amateur marathon athletes in the short- and relative long-time term after marathon. The results proved that the T2* value had changed to some extent, but the long-term impact of the marathon needed to be judged, so further follow-up and increasing the sample capacity were necessary. In addition, the time span of first measurement after marathon was large (12 h). Despite these limitations, this study still demonstrated statistically significant results indicated biochemical changes in knee cartilage after a marathon.

CONCLUSION

In conclusion, biochemical imaging was more sensitive than morphological examinations to study early changes in knee cartilage. The T2* values of knee cartilage in amateur marathon runners showed a "first rising and then decrease" trend, suggested

that articular cartilage had a degree of reversible change during marathon running. The TLP and TMA subregions needed follow-up after marathon, so as to avoid irreversible cartilage injury due to high exercise intensity.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This paper was approved by all authors. Availability of data and material: The datasets used during the current study are available from the corresponding author upon request.

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