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ORIGINAL

MEDICAL IMAGING-BASED PHYSIOLOGICAL CHARACTERIZATION AND PERFORMANCE PREDICTION IN ATHLETES

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ABSTRACT

The application of medical imaging in the physiological characterization of athletes covers multiple aspects such as injury diagnosis and monitoring, physiological structure assessment, preventive examination, and body change monitoring, which is of great significance in safeguarding athletes' health and improving their competitive performance. Field hockey is a high-intensity sport with intense confrontation, and the high incidence of knee injuries is a characteristic of athletic injuries in field hockey players. Early detection and treatment of articular cartilage injuries are of great significance to the performance of athletes' level of play and the extension of athletic injurie life. T2 mapping is a widely used cartilage MR imaging technique with high sensitivity to cartilage biochemical changes. In this paper, the T2 mapping technique was used to image the kneecap cartilage of field hockey athletes and healthy youths, to investigate the effect of field hockey on athletic injurie and the physiological characteristics of kneecap cartilage injury and to predict the development of the injury.

KEYWORDS: medical image; physiological characterization; athletic injurie

1. INTRODUCTION

Medical imaging plays an important role in the physiological characterization of athletes. Through the use of various medical imaging techniques, such as X-rays, CT scans, MRIs, and ultrasound, the bones, muscles, joints, and internal organs of an athlete can be viewed and evaluated in a comprehensive and non-invasive manner. Imaging technology can help physicians and professionals diagnose and monitor injuries and illnesses that athletes may encounter during training and competition (Guermazi et al., 2017). In addition, medical imaging can be used to assess an athlete's body composition, muscle development, and bone structure to optimize training programs and prevent athletic injuries.

The application of medical imaging in physiological profiling of athletes can provide comprehensive physiological information to help professionals better understand athletes' physical conditions, plan personalized training programs, and identify and address potential health problems in a timely manner. With the rapid development of the Internet of Things as well as artificial intelligence technology (Chen, Han, Zhang, You, & Zheng, 2023; Chen, Li, et al., 2023; Li & Cao, 2023), automatic assessment and early warning of athletic injuries is possible based on imaging data or daily monitoring data of athletes. The application of medical imaging in the physiological characterization of athletes covers a variety of aspects such as injury diagnosis and monitoring, physiological structure assessment, preventive examination, and monitoring of body changes, which is of great significance in safeguarding the health of athletes and improving their competitive performance.

Through medical imaging technology, it is possible to monitor the physical changes of athletes after long-term high-intensity training, including changes in indicators such as muscle hypertrophy, fat content and bone density. Medical imaging can help assess the skeletal structure, muscle development, and joint health of athletes; regular medical imaging can help detect potential health problems at an early stage, prevent athletic injuries, and improve the overall health of athletes (ABDULLAH, ABDULLAH, ZIYADI, & AL-FAIZ, 2022).

Figure 1: Schematic diagram of field hockey sports movements

Field hockey is a high-intensity sport with intense confrontation, as shown in Fig. 1. The athletes need to frequently perform rapid change of direction and acceleration movements during the game and training, which may cause the knee joint to bear excessive pressure on the Bin cartilage to cause injuries. The long period and large load of training make athletes improve their athletic ability, but at the same time, athletes accumulate different degrees of injuries, and serious injuries will cause the early termination of athletic career. The high incidence of knee injuries is a characteristic of athletic injuries in field hockey players, and the earliest knee injuries are injuries to the articular cartilage, and the patellar cartilage is most often involved (Orooj, Nuhmani, & Muaidi, 2016). Therefore, early detection and treatment of articular cartilage injuries are of great significance to the performance of athletes' game level and the extension of their athletic life.

At present, magnetic resonance examination is recognized as the imaging method of choice for articular cartilage examination, but conventional MRI sequence can only understand the thickness and morphological changes of articular cartilage, so some new techniques to study the tissue composition of articular cartilage have been carried out one after another, such as T_2 mapping, T1ρ, DWI, MTC, and 23Na imaging. The emergence of these new techniques has led to the development of the evaluation of articular cartilage from morphology to functionality, and to the construction of an evaluation system of the morphology-function relationship (Absil, Diao, & Diallo, 2021).

MR T_2 mapping is a commonly used technique to study the physio pathological changes of articular cartilage at home and abroad in recent years. By measuring the MR T_2 relaxation time to quantitatively analyze the changes of the composition of articular cartilage tissue, it can provide an objective and quantitative index to detect the disease, monitor the progression of the disease, and be helpful in guiding the treatment.

T_2 mapping is a cartilage MR physiological imaging technique that is widely used at home and abroad, and has been confirmed in both animal and human experiments, with high sensitivity but low specificity in response to biochemical changes in cartilage (Knecht, Vanwanseele, & Stüssi, 2006). The T_2 value is mainly influenced by the structural anisotropy of articular cartilage tissue, which is related to collagen fibrillar protein content, alignment direction and water content. Currently, more studies have been conducted on the T_2 value of early cartilage degeneration in OA, but there is still a big controversy among scholars about the quantitative assessment of different degrees of cartilage damage, and no consensus has been reached on whether there is any difference in the T_2 value of different degrees of cartilage damage.

Domayer et al (Domayer et al., 2008) concluded that the T_2 map reflects information about the biochemical composition of cartilage structure. T_2 maps are used as a noninvasive technique in clinical practice, and a number of studies have initially demonstrated the use of T_2 maps in large weight-bearing joints such as the knee. Welsch et al (G. Welsch et al., 2009) found that the thickness of cartilage gradually decreases with age and the T_2 value also decreases through animal experiments. Literature (Mosher et al., 2005) demonstrated a decrease in T_2 values of articular cartilage surfaces after exercise compared to before exercise. Although there are various factors affecting cartilage, the T_2 values of degenerated cartilage are higher than normal. Welsch et al (G. H. Welsch et al., 2009) compared the laminar distribution of articular cartilage by means of 3D-FS-SPGR and T_2 maps, and showed that the T_2 maps showed that the cartilage of the patella and the medial femoral condyle had higher T_2 values after arthroscopic treatment compared with that of healthy individuals, whereas no significant difference was found between the two in the 3D-FS-SPGR sequence.

T_2 mapping is mainly used for general osteoarthritis, and the diagnostic standard is not uniform, and it has not been applied to the diagnosis of early cartilage degeneration in athletic injuries; T_2 mapping pseudo-color mapping from the structure of the direct observation of cartilage injury has also been reported, and it has not been reported that it is applied to the study of cartilage injury of the knee joint of field hockey players.

In this paper, we investigated the magnetic resonance T_2 mapping images of early cartilage injury in the knee joint of field hockey players, explored the clinical application value of T_2 mapping in early articular cartilage injury, and thus revealed the relationship between patellar cartilage injury and T_2 value and the correlation between patellar cartilage T_2 value and training time in field hockey players. By observing the distribution of patellar cartilage on the T_2 mapping pseudo-color map, the T_2 value changes of early damaged patellar cartilage equivalent to that of normal patellar cartilage were determined, which provided a prediction of potential patellar cartilage damage.

2. T_2 mapping in early articular cartilage damage

2.1 Principle of MR T_2 mapping technique

T_2 is the time required for the transverse magnetization relaxation to decay to 37% of the maximum signal strength, and is a metric that can be quantitatively determined on T_2 mapping. T_2 mapping uses a multifaceted multi-echo spin-echo sequence scanned with the same repetition time and several different echo times to obtain a series of T_2WI images; the T_2 value for each voxel in the $T_2$2WI map is then calculated from Eq $S(t) = S_0 \exp(-t/T_2)$.

$S(t)$ is the tissue signal intensity obtained at different echo times, S_0 is the signal intensity at t=0, and T_2 is the transverse relaxation time. Then pixel-to-pixel conversion is performed, and the raw data are logarithmically converted and reconstructed by least squares linear regression to T_2 mapping, which can be quantitatively analyzed in gray scale or color scale (see Figs. 2, 3). Then the region of interest is selected for measurement, and the T_2 value of the tissue is measured, so as to achieve the purpose of quantitatively evaluating the structural biochemical properties of the tissue (Goodwin, Wadghiri, & Dunn, 1998).

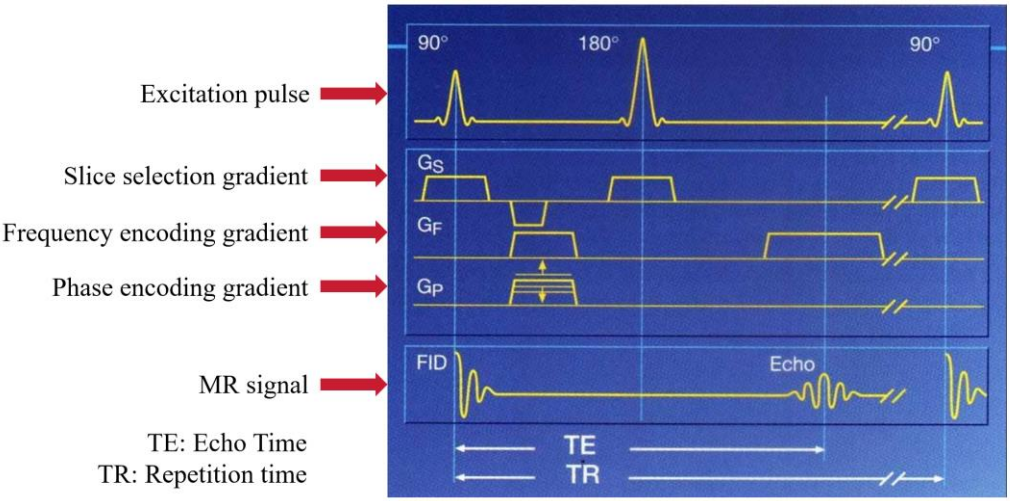


Figure 2: Schematic of Pulse Sequence

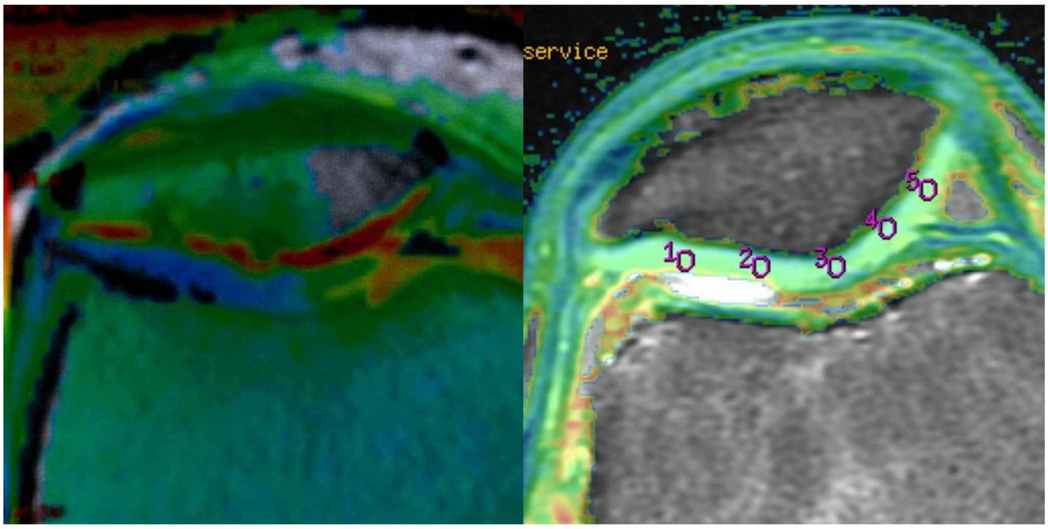


Figure 3: T_2 mapping uses multiple 180-degree echo pulses, measures the T_2 decay curve, and calculates the T_2 value. In Functool software, color is used to represent the magnitude of the T_2 value. Normal cartilage has a short T_2 value with a low color scale of blue, and when cartilage is destroyed and water enters the cartilage, the T_2 value is lengthened and the color scale rises to green or even red.

2.2 T_2 mapping technique in knee cartilage injury

T_2 mapping is a widely used cartilage MR physiological imaging technique at home and abroad, both in animal experiments and human experiments have been confirmed, it has a high sensitivity to the response of cartilage biochemical alterations, but the specificity is low (Quaia et al., 2008). In the early stage of articular cartilage injury, the cartilage microenvironment is altered, with abnormal chondrocyte function and disturbed ECM metabolism, which, in turn, causes the type II collagen fiber skeleton of the cartilage surface layer to take the lead in degeneration. The fracture of the reticular skeleton causes the proteoglycans folded and aggregated therein to deconvolute and disperse, and the expansive osmotic pressure of the ECM increases significantly, increasing the water content of cartilage.

Accompanied by the continued loss of proteoglycans, the residual proteoglycans have a greater stretching space, exposing more anionic interstitial space, which further also increases the water content. Numerous foreign studies have found that the T_2 value of articular cartilage is closely related to free water and is affected by the collagen fiber content and its alignment direction, while the longitudinal spatial distribution of the T_2 value may be affected by the loss of proteoglycans.

Taken together, it seems that structural disruption of collagen fibers, changes in collagen fiber orientation, loss of proteoglycans, and increased water content in articular cartilage all lead to an increase in cartilage T_2 values. By measuring the T_2 value and spatial distribution of articular cartilage, T_2 mapping is expected to sensitively reflect the degeneration of cartilage, which belongs to the MR physiological imaging technique of articular cartilage, and is widely used at home and abroad.

3. Research Objects and Methods

3.1 Research Objects

3.1.1 Sports Trauma Group

There were 16 cases of professional field hockey players, all of them were male, right-handed (right-handed, used to use the right leg), aged 17-26 years old (mean age 20.51 years old), weighing 58-80 Kg (mean 69.35 Kg), with a total of 32 knee joints. All of the above athletes had a history of professional training for more than 3 years and trained for about 6 hours a day. The right leg was the supporting leg in this group of field hockey players, and 16 of them had a history of right knee pain of varying degrees.

3.1.2 Control group

There were 14 asymptomatic young volunteers, all of them were male, right leghorn, aged 18-30 years old (mean age 22.45 years old), weighing 55-73Kg (mean 67.42 Kg), with a total of 28 knee joints. All volunteers were in good health, with no knee discomfort, no history of trauma or surgery, no history of heavy physical activity, and their body weights were within the normal range; they had not used any medication in the last 1 month. All volunteers understood the purpose of the experiment, the experimental procedures, and agreed to participate in the study.

3.2 Magnetic resonance scanning equipment

The MR examination was performed using a 1. 5T GE Signa HD MR scanner (see Fig. 4) with a gradient field strength of 23 mT and a gradient field switching rate of 120 mT /Ms. The scanning coil was an 8-channel knee phased-array coil from GE. Figs. 4 b and c show the structure of the MR knee coil when it is opened and wrapped around the knee leg to be tested, respectively.

Figure 4: Schematic of the scanning equipment

a. The 1. 5T GE Signa HD MR scanner; b. and c are the magnetic resonance knee coils.

3.3 Experimental Methods

All subjects (sports trauma group and control group) rested quietly for more than 30 minutes before entering the MR scanning room to undergo scanning, so that the patellar cartilage of the knee joint could get sufficient rest, and try to avoid weight-bearing deformation of the patellar cartilage of the knee joint, which would constitute an error in the measurement results. The subjects were placed in a supine position, with the foot advanced, one knee placed in the coil on the surface of the knee joint, the center of the examined patella was located in the center of the coil, the examined knee joint was flexed by 5°~10°, and the limb was fixed by filling sponge pads around the limb, and at the same time, the importance of keeping the limb posture fixed was explained to the subjects.

During the test, the subject was scanned in sagittal (all sections of the body longitudinally cut into left and right parts in an anterior-posterior direction) and axial (all sections of the body longitudinally cut into upper and lower parts) (of which sagittal T1WI was mainly used for axial localization, and the median level in the sagittal position was selected in the direction of roughly perpendicular direction to the patellofemoral articular surface to determine the axial position, usually 6 layers, and the axial position was scanned for PDWI and T_2mapping). The scanning parameters are shown in Table 1.

Table 1: MRI Scanning Parameters

MR SEQUENCE	TR(MS)	TE(MS)	ST/SD	NEX	MATRIX	FOV	SCAN TIME(S)
T1WI	420	11	4/0.5cm	1	320×256	16×16	135
PDWI	2650	30.2	4/0.5cm	2	320×256	16×16	173
T_2 MAPPING	1300	15,30,45, 60,75,90	4/0.5cm	1	320×256	16×16	257

3.4 Post-processing of images and data

The obtained T_2 mapping raw data were transferred to GE ADW 4.2 workstation and post-processed by Functool software, resulting in T_2 mapping pseudo-color maps, andT_2 values were measured on the T_2 mapping. The three consecutive layers (layers a, b, and c) with the largest volume of patellar cartilage in the knee joint were selected, and the target regions (ROIs) were drawn along the contour of the patellar cartilage, with a diameter of about 5 mm, and each layer of the patellar cartilage was divided into 5 regions (see Fig. 5), including the medial region, the partial medial region, the central region, the lateral region, and the posterolateral region, so that each piece of the patellar cartilage had 15 target regions.

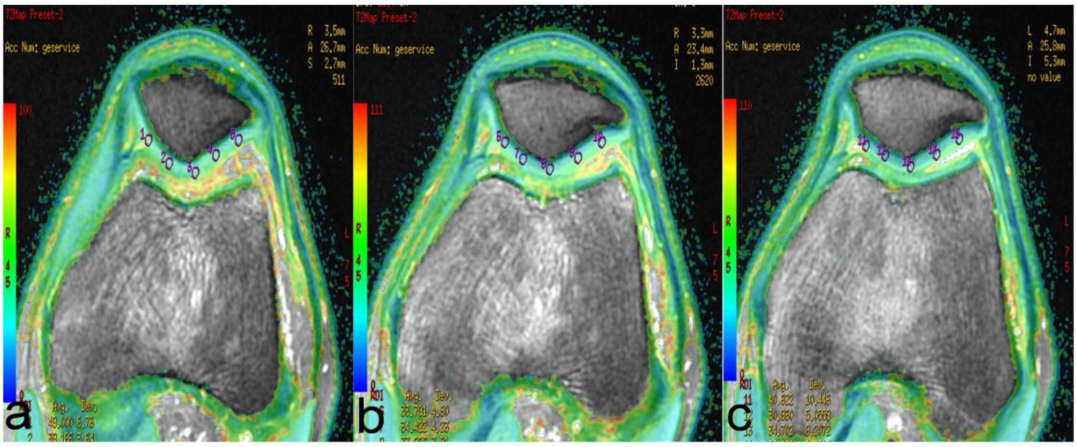


Figure 5: Pseudo-color map T_2 values, distribution of 15 target areas

As shown in Fig. 5 above, a, b, and c are three consecutive levels of the patellar cartilage axis, and the target regions 1-15 are located within the patellar cartilage, with regions 1, 6, and 11 being the lateral zone, regions 2, 7, and 12 being the paravaginal zone, regions 3, 8, and 13 being the central zone, regions 4, 9, and 14 being the paravaginal zone, and regions 5, 10, and 15 being the medial zone.

Principles of target area selection: 1) select a larger threshold, so that the patellar cartilage can be clearly displayed; 2) fusion of the same scanning level of PDWI images to ensure that the patellar cartilage is properly selected; 3) minimize the ROI, the selection of ROI should be avoided to avoid the knee joint bone tissues and articular cavity effusion. In addition, the selection and measurement of ROI are greatly influenced by human factors, and the T_2 value in this paper was measured twice by the same physician at different times.

3.5 Statistical processing

T_2 values were obtained for each patellar cartilage measurement for 15 target regions, and the average T_2 value for the patellar cartilage derived by averaging these 15 T_2 values was calculated using equation (1):

$$T_2av = \frac{\left(T_2^1 + T_2^2 + \cdots + T_2^{15}\right)}{15} \qquad (1)$$

The following statistical treatments were performed using the SPSS 16.0 software package, and $P < 0.05$ was considered a statistical difference. (1) A paired-sample t-test was used to analyze the differences in the T_2av of the patellar cartilage bilaterally in the field hockey players and bilaterally in the healthy volunteers. (2) A two-sample t-test was used to analyze the differences in T_2 values of patellar cartilage in the right knee of the two groups (field hockey players and healthy volunteers), and the differences in T_2 values of patellar cartilage in the left knee of the two groups (field hockey players and healthy volunteers).

4. Experimental results

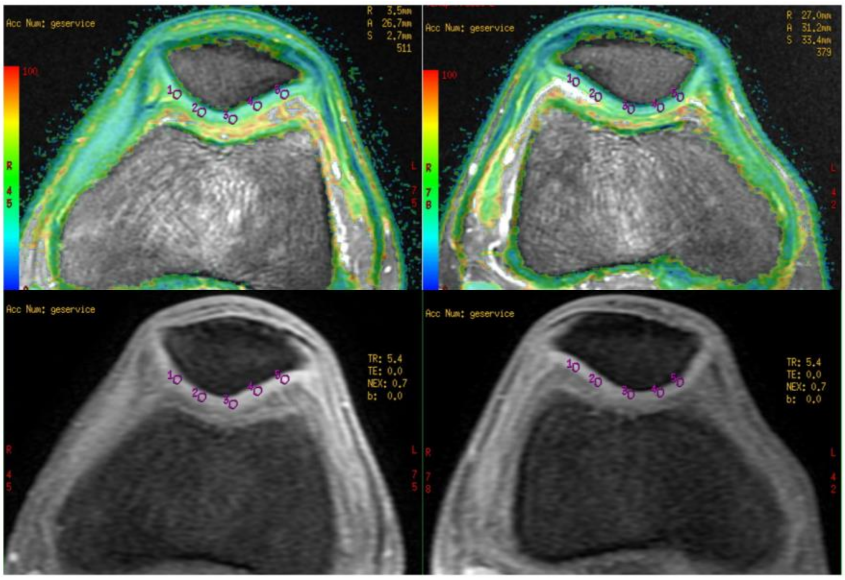
4.1 Overall characteristics of T_2mapping in experimental and control groups

In healthy volunteers, bilateral patellar cartilage showed high signal on PDWI images in the transverse position, and no obvious defects or signal abnormalities were seen. On the fitted T_2 mapping pseudo-color images, the patellar cartilage was seen to be stratified, with grass-green to dark-blue signal changes from the surface to the subchondral bone interface, with no significant differences between the two sides. See Fig. 6 for measurements of two typical healthy volunteers. The bilateral patellar cartilage of the field hockey players showed high signal on the PDWI images in the transverse position, and no obvious defect or signal abnormality was seen; however, on the fitted T_2 mapping pseudo-color maps, an increase in the color gradient of the patellar cartilage was seen. Among them, 11 athletes (11/16) had more obvious color gradient increase in the lateral and deviated lateral regions of the bilateral patellar cartilage, and even part of the structure was blurred, with the blue range narrowing and the green range expanding and shifting to yellow. As shown in Figs 7 and 8, in the field hockey player, the patellar cartilage was seen to be altered in stratification, with an increase in color scale, a decrease in the blue range, an increase in the green range, and the emergence of some few yellow areas, which were more obvious in the lateral and deviated lateral areas of the right patellar cartilage, and the measured T_2 value was elevated, which was in the cartilage degeneration grade I. In the healthy volunteers, only 2 cases (2/14) had similar manifestations.

Only 2 cases (2/14) of healthy volunteers had similar manifestations. There was a significant difference between the two groups of cases by four-cell table chi-square test, P=0.01, as shown in Table 2, 11 athletes (11/16) in the field hockey players had chondrodegeneration grade I, and only 2 cases (2/14) in the healthy volunteers had a similar manifestation, and the signals of grade I degenerated patellar cartilage in the healthy volunteers were more uniform, and the elevation of the color gradient was not as pronounced as that in the sports trauma group, as shown in Figs. 7 and 8.

Table 2: Statistics of patellar cartilage in Sports Trauma Group and Control Group

GRADING OF CARTILAGE LESIONS	CONTROL GROUP	SPORTS TRAUMA GROUP	P VALUE
GRADE 0	11	5	0.01
GRADE I	3	11	



Left

Right

Figure 6: Healthy volunteer, male, 22 years old, T_2 mapping pseudo-color image shows that the patellar cartilage is stratified, from the surface to the subchondral bone interface showing grass green to dark blue signal changes, with no significant difference between the two sides; the patellar cartilage is high signal on the PDWI image, with no obvious defect or signal abnormality.

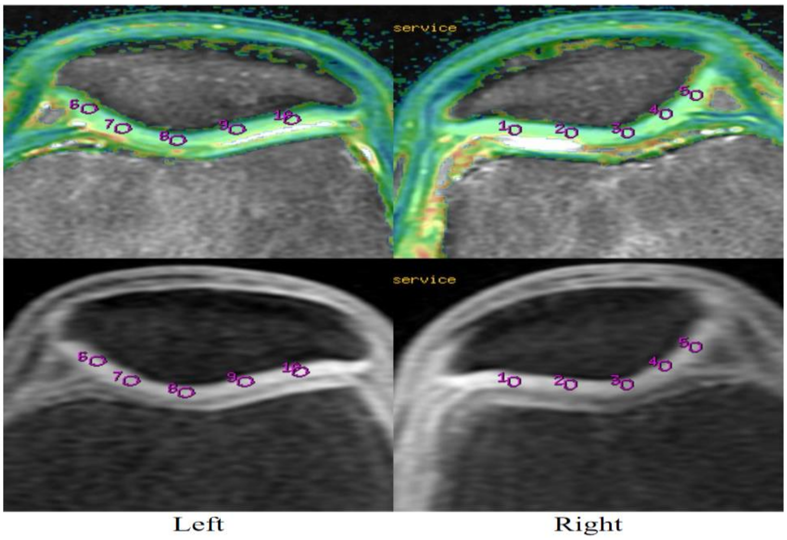


Figure 7: Hockey player, male, 19 years old, T_2 mapping pseudo-color map shows stratified changes, with an increase in the color scale of the patellar cartilage, with a decrease in the blue range, an increase in the green range, and the appearance of some few yellow areas, which are more pronounced on the right side of the patellar cartilage in the posteromedial and paramedial areas, and an increase in the measured T_2 value.

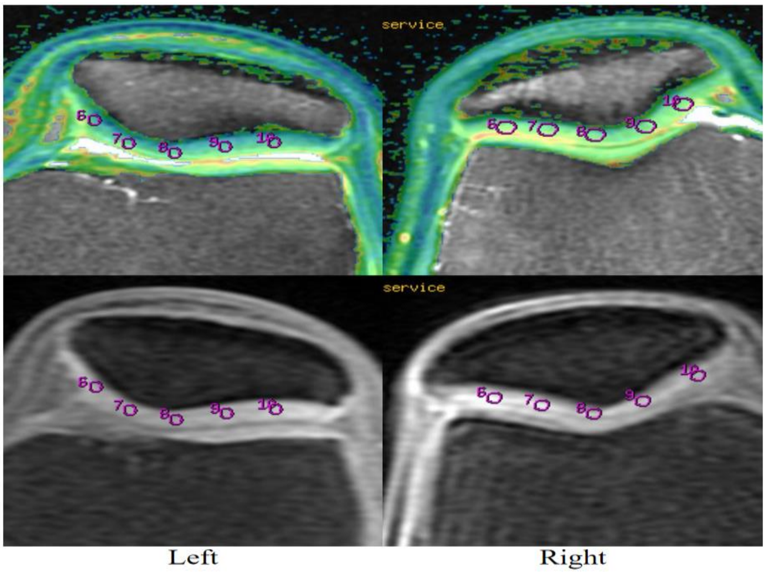


Figure 8: Hockey player, male, 22 years old, T_2 mapping pseudo-color map shows stratified changes, with increased color gradation of the patellar cartilage, a decrease in the blue range, an increase in the green range, and the appearance of some yellow areas, which are more pronounced on the right side of the patellar cartilage in the posterolateral and deviated posterolateral areas, with an elevated T_2 value measured.

4.2 Comparison of Bilateral T_2av Within Groups

4.2.1 Comparison of bilateral T_2av in the athletic injurie group

The sports trauma group included 16 cases with 32 patellar cartilages.

The T_2 values of both knees are listed exhaustively in Table 4. The T_2av of the right patellar cartilage ranged from 37.91 to 46.38 (ms), with a mean of 41.29 ± 5.26 (ms); The T_2av of the left patellar cartilage ranged from 35.08 to 42.39 (ms), and the mean value was 39.92±4.69 (ms); The T_2av of the right patellar cartilage was increased compared to the left patellar cartilage, which was significant by paired samples t-test, $t = 2.58$, $P = 0.02$ ($P < 0.05$) (see Table 4).

4.2.2 Comparison of bilateral T_2av in control group

The control group included 14 cases with 28 patellar cartilages. Their T_2 values are also listed exhaustively in Table 4. The T_2av of the right patellar cartilage ranged from 32.79 to 37.76 (ms), with a mean value of 35.60 ± 4.26 (ms); the T_2av of the left patellar cartilage ranged from 32.71 to 37.52 (ms), with a mean value of 35.01 ± 3.87 (ms). The T_2av of the right patellar cartilage was slightly higher than that of the left patellar cartilage, and the paired-samples t-test showed that there was no significant difference with $t=1.47$ and $P=0.16$ ($P ＞0.05$) (see Tables3 and 4).

Table 3: Bilateral patellar cartilage T_2av in both groups

SERIAL NO.	SPORTS TRAUMA GROUP T_2 VALUES (MS)		CONTROL GROUP T_2 VALUES (MS)	
	Right	Left	Right	Left
1	36.303882	35.281741	38.654407	37.302825
2	40.774546	42.503440	33.684006	37.255786
3	43.716941	40.098918	37.676259	34.004355
4	44.277032	39.299839	35.207838	34.126163
5	42.219026	41.579771	32.230302	32.507950
6	46.490012	41.312130	36.438947	34.406954
7	41.813064	40.329435	37.000009	34.183936
8	40.495578	40.546207	32.767095	35.502245
9	39.562499	37.809133	35.348314	35.884192
10	39.595601	39.934894	36.281437	36.883955
11	41.328500	41.398989	35.374922	34.803742
12	42.908079	42.848145	34.595233	34.153720
13	41.236847	37.508498	37.985283	36.125807
14	40.721684	41.723559	34.679230	32.575889
15	43.710026	43.989030		
16	41.370011	36.349691		

Table 4: Differences in bilateral patellar cartilage T_2av between the two groups of subjects

T_2AV	RIGHT	LEFT	T VALUE	P VALUE
SPORTS TRAUMA GROUP	41.29±5.26	39.92±4.69	2.58	0.02
CONTROL GROUP	35.60±4.26	35.01±3.87	1.47	0.16

5. Discussions

5.1 T_2 mapping imaging of patellar cartilage in healthy knees

The normal side of the patellar cartilage showed high signal on the transverse PDWI image, and no obvious defect or signal abnormality was seen; In the fitted T_2 mapping pseudo-color images, the patellar cartilage was seen to be stratified, showing grass-green to dark-blue signal changes from the surface to the subchondral bone interface, reflecting the spatial differences in the longitudinal distribution of T_2 values in the patellar cartilage. This phenomenon is related to the anisotropy of articular cartilage, especially to the content, alignment direction and water content of collagen fibers in each layer of cartilage, which leads to lower T_2 values in the deeper layer of cartilage (radial layer) and higher T_2 values in the surface layer.

5.2 T_2 mapping imaging of patellar cartilage in the knee joint of field hockey players

Abnormalities in T_2 mapping of articular cartilage damage can be broadly categorized into three types: first, focal elevation of T_2 values in articular cartilage, suggesting that these focal lesions may be manifestations of early degeneration. Second, the T_2 value of the whole layer of articular cartilage was generally elevated, and the T_2 mapping showed the increase of cartilage color scale. Thirdly, the heterogeneity of cartilage T_2 values increased, which showed that the OA cartilage in T_2 mapping not only had heterogeneous color gradient signals, but also had non-full-layer defects in some of the severe cases. In this paper, both right and left knees of the field hockey players had different degrees of degeneration, but the right patellar cartilage damage was more serious, and the corresponding discomfort symptoms of the knee joint appeared, and the left patellar cartilage damage was less serious, and the symptoms had not yet appeared, so it could be seen from the T_2 mapping pseudo-color maps that the athletes' bilaterally patellar cartilage color grades increased compared with those of the healthy volunteers.

Among them, 11 athletes (11/16) had higher color grades in the lateral area of bilateral patellar cartilage, and even part of the structure was blurred, the blue range was narrowed, the green range was expanded, and even shifted to yellow, and the signals in the PDWI sequence were slightly increased, but there was no obvious thinning or defects of the cartilage, which was in the cartilage degeneration grade I. Only 2 cases (11/16) in healthy volunteers had higher color grades than the healthy volunteers, which was not yet symptomatic. Only 2 cases (2/14) of healthy volunteers had similar manifestations, and there was a significant difference between the two groups of cases by the four-cell table chi-square test, P=0.01, and the data are shown in Table 2. The cartilage degeneration in field hockey players was different from the three cases of cartilage grade I degeneration in healthy volunteers:

(1) The horizontal range of cartilage degeneration color grades was wider in the field hockey players than in the healthy volunteers, which may be due to the wider area of cartilage damage in the field hockey players; (2) The range of areas with elevated cartilage degeneration color grades in field hockey players is deeper vertically than in healthy volunteers, the reason may be that the cartilage injury in field hockey players involves a deeper cartilage level; (3) The areas with elevated cartilage degeneration color gradient in field hockey players have more mixed signals than healthy volunteers, which may be due to the different degrees of cartilage damage, and the T_2 values in the areas with mixed signals are higher, which means that the damage is more serious.

Abnormalities in T2 values of articular cartilage damage can be categorized into three types: (1) Focal elevation of T_2 value of articular cartilage reflects the early degeneration of the lesion in the region; (2) Generalized increase in T_2 value of the whole layer of articular cartilage, which is manifested as an increase in the color scale of the whole layer of cartilage on the T_2 mapping pseudo-color map; (3) The heterogeneity of T_2 values in the whole layer of cartilage increased, and the T_2 mapping pseudo-color map showed that the damaged cartilage not only had mixed signals of color grades, but also had defects in the non-whole layer in severe cases.

The color gradient of the cartilage portion located in the lateral area of the patellar cartilage and the lateral area of the patellar cartilage was more obvious, and the proportion was higher, suggesting that the degree of injurie was more serious, which was related to the repeated flexion and torsion of both knees and the increase of the lateral pressure during the athletic activities. The sensitivity of T_2 mapping was higher, and 68.8% of field hockey players with knee symptoms were found to have T_2 mapping signal changes in articular cartilage, but the specificity could not be evaluated accurately due to the lack of histopathological control.

5.3 Biochemical changes in T2 mapping reflecting patellar cartilage damage

T_2 mapping pseudo-color maps can detect early damage to patellar cartilage in field hockey players, showing changes in the color scale of articular cartilage when conventional magnetic resonance sequences have not detected articular cartilage abnormalities, with cartilage damage increasing in blue and decreasing in blue, and expanding in green, even shifting to yellow, with mixed signals and even blurring of some of the structures. Measurement of the T_2 value in the area of the corresponding signal abnormality can be used to quantify, compare, and review the extent of the lesion. At the same time, the performance of T_2 mapping on articular cartilage damage also reflects the cause and molecular mechanism of articular cartilage damage: early damage to articular cartilage, the microenvironment of the cartilage is changed, at this time, the chondrocyte function is abnormal, and the metabolism of the ECM is disturbed, which further causes the degeneration of the type II collagen fibers skeleton of the cartilage surface layer first. With the fracture of the reticular skeleton, the proteoglycans folded and aggregated therein were deconvoluted and dispersed, and the expansive osmotic pressure of the ECM was further increased, and the water content of the cartilage was increased. This is accompanied by the continued loss of proteoglycans, leaving greater stretching space for the residual proteoglycans, which can expose more anionic interstitial space, and this also further increases the cartilage water content, which leads to an increase in the T_2 value of articular cartilage.

Noyes' revised grading scale is commonly used: Grade 0, normal articular cartilage; Grade I, signal change within the cartilage; Grade II, partial cartilage loss, less than 50% of the total thickness; Grade III, cartilage damage reaches more than 50% of the total thickness; Grade IV, total loss of articular cartilage. The decomposition of cartilage degeneration needs to be evaluated in combination with MR routine sequences, and there is currently no standard for grading cartilage damage by T_2 mapping alone, but in this paper, we determined the average T_2 value of healthy volunteers, and then set the damage threshold on the basis of this, so that we can preliminarily determine the degree of cartilage damage in the early stage of the disease.

5.4 Mechanisms of knee injuries in field hockey players

The knee joint is a high incidence of athletic injuries in ball sports, and field hockey is no exception. The knee is the largest movable joint, which can only do flexion and extension movements, but can have passive internal and external rotation and medial and lateral movements under the condition of semi-flexion position. In field hockey, athletic injuries of the knee joint are very common due to the requirements of physical and technical movements, and the types of knee injuries include: patellar strain and patellar chondromalacia, meniscus injuries, patellar tendinopathy of the end of the patellar tendon, and traumatic synovitis.

In competition and training, athletes use a specialized hockey stick to control the ball, the stick is about 0.9 meters long, usually always held by the right hand, and can only hit the ball with the stick, so a lot of ball handling and defensive techniques require joint movements such as torso flexion or rotation. Due to the technical characteristics of field hockey, the bilateral knee joints are often in a semi-flexed position to accomplish sudden starts, sharp stops, and sharp left and right turns. Sudden change of direction during high-speed running (sharp turn, sharp stop, punt, pad, make-up shot, etc.) and other technical actions, resulting in the knee joint is often in a state prone to damage the patellofemoral cartilage, coupled with over-training, the knee joint of the field hockey player is very easy to be injured.

Field hockey players' bilateral knee joints are often in a semi-flexed position when they hit the ball, which is a state prone to damage the patellofemoral cartilage. Most field hockey players hold the ball in their right hand and their center of gravity tends to be on the right side of the ball, which causes inconsistencies in the trajectory, point of gravity, and mechanical load of the knee joints on both sides of the body, resulting in not only easy injuries, but also different degrees and locations of injuries. In addition, when the field hockey player completes the "pull shot" movement, the knee joint of the supporting leg is in the 90° flexion position, fixed, and completes the strong twisting action, which also makes the field hockey player's knee joint of the supporting leg increase the chance of injury.

Because of the technical characteristics of field hockey, the athlete's right knee, as the supporting leg, not only bears significant pressure, but also repeatedly twists, and the lateral zone, as the focus point of the stress lever, is subjected to the greatest load, so the right side of the field hockey player is more prone to injury, and the degree of injury in the lateral zone is more serious. The peak moment values of the extensor muscles were higher than those of the flexor muscles in both the left and right knees; the flexor-extensor ratio was higher in the left than in the right. The low ratio of flexor and extensor muscles in the knee joint is easy to cause flexor muscle strain or knee joint injury. The right side of our male field hockey players is more prone to injury than the left side.

6. Conclusion

Field hockey players have a high incidence of knee injuries due to their athletic injuries, the earliest of which is the articular cartilage, and the patellar cartilage is most often involved. T_2 mapping is a widely used MR cartilage physiological imaging technique at home and abroad, and its value has been confirmed in both animal and clinical experiments. The sequence has greater sensitivity and specificity to articular cartilage damage, and can quantify the extent of early damage to articular cartilage, reflecting changes in the biochemical structure of the degenerated cartilage to predict the damage before the cartilage appears to be morphologically altered, while the MR sequence can be repeated many times, which is helpful to predict the recovery of the articular cartilage in athletes. The main conclusions of this study are as follows:

(1) Compared with the healthy volunteers, the patellar cartilage of the field hockey players increased in color scale on the pseudo-color map, and the right lateral patellar cartilage and lateral patellar cartilage were more obvious, and even part of the structure was fuzzy, reflecting that the lateral patellar

cartilage and lateral patellar cartilage were more prone to injuries caused by the prolonged training and competitions of the field hockey players, and they should be focused on it.

(2) Field hockey players had uneven cartilage damage in both knees, and their right patellar cartilage damage had the highest T_2 values in the right patellar cartilage's lateral and paramedial regions; their left patellar cartilage had the highest values in the lateral, paramedical, and central regions.

(3) Field hockey players are similar to athletes in soccer and marathon, and they are all more prone to knee injuries, but field hockey players develop injuries to the lateral and deviated lateral regions of the patellar cartilage at an earlier age; therefore, MRI is important for the early detection of knee athletic injuries in field hockey players.

REFERENCES

ABDULLAH, A. H. J., ABDULLAH, S. A., ZIYADI, M. S., & AL-FAIZ, N. A. (2022). Investigation of changes in the fish assemblage building and abundance in the Garmat Ali River, Southern Iraq. *FishTaxa-Journal of Fish Taxonomy, 25*.

Absil, P.-A., Diao, O., & Diallo, M. (2021). Assessment of COVID-19 hospitalization forecasts from a simplified SIR model. *Letters in Biomathematics*. doi:10.30707/LiB8.1.1682013528.154572

Chen, J., Han, P., Zhang, Y., You, T., & Zheng, P. (2023). Scheduling energy consumption-constrained workflows in heterogeneous multi-processor embedded systems. *Journal of Systems Architecture, 142*, 102938.

Chen, J., Li, T., Zhang, Y., You, T., Lu, Y., Tiwari, P., & Kumar, N. (2023). Global-and-local attention-based reinforcement learning for cooperative behaviour control of multiple UAVs. *IEEE Transactions on Vehicular Technology*.

Domayer, S., Kutscha-Lissberg, F., Welsch, G., Dorotka, R., Nehrer, S., Gäbler, C., . . . Trattnig, S. (2008). T2 mapping in the knee after microfracture at 3.0 T: correlation of global T2 values and clinical outcome–preliminary results. *Osteoarthritis and cartilage, 16*(8), 903-908.

Goodwin, D. W., Wadghiri, Y. Z., & Dunn, J. F. (1998). Micro-imaging of articular cartilage: T2, proton density, and the magic angle effect. *Academic Radiology, 5*(11), 790-798.

Guermazi, A., Roemer, F. W., Robinson, P., Tol, J. L., Regatte, R. R., & Crema, M. D. (2017). Imaging of muscle injuries in sports medicine: sports imaging series. *Radiology, 282*(3), 646-663.

Knecht, S., Vanwanseele, B., & Stüssi, E. (2006). A review on the mechanical quality of articular cartilage–implications for the diagnosis of osteoarthritis. *Clinical Biomechanics, 21*(10), 999-1012.

Li, Y., & Cao, J. (2023). Adaptive binary particle swarm optimization for WSN node optimal deployment algorithm. *IECE Transactions on Internet of Things, 1*(1), 1-8.

Mosher, T. J., Smith, H. E., Collins, C., Liu, Y., Hancy, J., Dardzinski, B. J., & Smith, M. B. (2005). Change in knee cartilage T2 at MR imaging after running: a feasibility study. *Radiology, 234*(1), 245-249.

Orooj, M., Nuhmani, S., & Muaidi, Q. I. (2016). Common injuries in field hockey. *Saudi Journal of Sports Medicine, 16*(1), 20-27.

Quaia, E., Toffanin, R., Guglielmi, G., Ukmar, M., Rossi, A., Martinelli, B., & Cova, M. A. (2008). Fast T2 mapping of the patellar articular cartilage with gradient and spin-echo magnetic resonance imaging at 1.5 T: validation and initial clinical experience in patients with osteoarthritis. *Skeletal Radiology, 37*, 511-517.

Welsch, G., Trattnig, S., Domayer, S., Marlovits, S., White, L., & Mamisch, T. C. (2009). Multimodal approach in the use of clinical scoring, morphological MRI and biochemical T2-mapping and diffusion-weighted imaging in their ability to assess differences between cartilage repair tissue after microfracture therapy and matrix-associated autologous chondrocyte transplantation: a pilot study. *Osteoarthritis and cartilage, 17*(9), 1219-1227.

Welsch, G. H., Mamisch, T. C., Quirbach, S., Zak, L., Marlovits, S., & Trattnig, S. (2009). Evaluation and comparison of cartilage repair tissue of the patella and medial femoral condyle by using morphological MRI and biochemical zonal T2 mapping. *European Radiology, 19*, 1253-1262.