Thieme

Preclinical Cartilage Changes of the Knee Joint in Adolescent Competitive Volleyball Players: A Prospective T2 Mapping Study

Präklinische Knorpelveränderungen des Kniegelenkes bei jugendlichen Volleyballern im Leistungssport: Eine prospektive T2-Mapping-Studie

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ABSTRACT

Purpose To investigate the potential effects of volleyball as a competitive sport in adolescence on the cartilage of knee joints using T2 mapping in MRI and identification of preclinical cartilage changes. Volleyball as an impact sport often leads to damage of the knee joint cartilage in adulthood. As T2 mapping is widely available and highly capable of detecting cartilage changes prior to conventional MRI sequences, such a detection may allow adolescent volleyball players to change their training regime before structural damage can occur to the cartilage and pose the risk of osteoarthritis.

Materials and Methods Comparative study of the patellar, femoral, and tibial cartilage of 60 knee joints using T2 mapping on 3 T MRI. In each case, both knees of 15 adolescent competitive volleyball athletes were compared with 15 controls.

Results In the group of competitive athletes, more focal cartilage changes were detected in the medial facet of the patellofemoral cartilage and in the medial femoral condyle of the knee joint cartilage ($p = .01$ and $p < .05$, respectively). Furthermore, the latter showed a diffused increase in maximal T2 mapping values ($p < .04$ right and $p = .05$ left). The distribution of changes seems to further depend on the player's position.

Conclusion In adolescent volleyball players in competitive sports, T2 mapping demonstrates early cartilage changes in both the patellofemoral and medial femoral cartilages. The distribution of lesions depends on the player's position. Since the cascade from T2 relaxation time increase to conspicuous cartilage damage is well established, early counter-regulation (e. g., adapted training profile, targeted physiotherapy, and appropriate muscle building training) has the potential to prevent later damage.

Key Points:

1. Volleyball as a competitive sport in adolescence leads to preclinical knee cartilage changes.
2. Cartilage changes are both focal and diffuse.
3. Jumping-intensive player positions seem to show more patellofemoral and running-intensive more condylar cartilage changes.
4. Early detection of these changes could prevent progression to cartilage damage through adapted training.

Citation Format

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ZUSAMMENFASSUNG

Ziel Es sollen die Auswirkungen von Volleyball als Leistungssport im Jugendalter auf den Knorpel der Kniegelenke mittels T2-Mapping in der MRT untersucht werden und nach präklinischen Knorpelveränderungen gefahndet werden. Volleyball auf Hochleistungsniveau führt als Impact-Sportart im Erwachsenenalter häufig zu Schäden am Kniegelenksknorpel. Das T2-Mapping des Kniegelenksknorpels in der MRT ist ein exzellentes

und breitflächig verfügbares Verfahren zur Detektion von diffusen und regionalen Knorpelveränderungen, noch bevor diese in den gängigen MR-Sequenzen wie PD-FS, T1 und T2 sichtbar werden. Dies kann den Betroffenen eine Verhaltensänderung ermöglichen, noch bevor sich strukturelle Knorpelschäden mit der Gefahr einer Arthrose etablieren können.

Material und Methoden Vergleichende MR-Untersuchung jeweils beider Kniegelenke von 15 jugendlichen Leistungssportlern im Volleyball mit 15 Kontrollen mittels T2-Mapping des retropatellaren Knorpels und des Kniegelenksknorpels.

Ergebnisse Bei den Leistungssportlern lassen sich sowohl am retropatellaren Knorpel im Bereich der medialen Facette als auch im Bereich des Deckknorpels der medialen Femurkondyle signifikant mehr fokale Knorpelveränderungen ($p = .01$ respektive $p < .05$) nachweisen als bei den Kontrollen. Der Knorpel der medialen Femurkondyle zeigt darüber hinaus diffus im gesamten Knorpel eine signifikante Steigerung der maximalen T2-Relaxationszeiten bei den Leistungssportlern ($p < .04$ rechts und $p = .05$ links). Die Verteilung der Veränderungen scheint zusätzlich von der Spielerposition abhängig zu sein.

Schlussfolgerung Bei adoleszenten Volleyballern im Leistungssport sind mittels T2-Mapping frühe Knorpelveränderungen sowohl am retropatellaren als auch am medialen femoralen Knorpel nachweisbar, wobei die Verteilung der Läsionen von der Spielerposition abhängt. Da die Abfolge aus T2-Relaxationszeiterhöhung zu offensichtlichen Knorpelschäden gut belegt ist, könnte eine frühe Gegenregulation (z. B. durch ein angepasstes Trainingsprofil, gezielte Physiotherapie und entsprechendes Muskelaufbautraining) spätere Schäden verhindern.

Kernaussagen:

1. Volleyball als Leistungssport im Jugendalter führt zu präklinischen Knieknorpelveränderungen.
2. Die Knorpelveränderungen zeigen sich sowohl fokal als auch diffus.
3. Sprungintensive Spielerpositionen scheinen eher retropatellare und laufintensive mehr kondyläre Knorpelveränderungen aufzuweisen.
4. Die Früherkennung dieser Veränderungen könnte durch adaptiertes Training das Fortschreiten hin zu manifesten Knorpelschäden verhindern.

Introduction

Both the patellofemoral cartilage and the covering cartilage of the femoral condyles and tibial plateau are composed of hyaline cartilage. Due to its structure, hyaline cartilage is ideally suited to absorb the strong forces acting on the knee joint, to distribute them, and to transmit them to the underlying bone. Its integrity is essential for the proper functioning of the knee joint. Because hyaline cartilage is a bradytrophic tissue with a low regenerative capacity [1], once damage occurs, it often does not result in complete healing, but instead results in defective healing with less resilient reparative cartilage. Secondary damage may then occur to the subchondral bone [2]. This cascade leads to premature wear and tear, that, if left untreated, can result in knee joint osteoarthritis [3]. The gradual degeneration of cartilage can be visualized through T2 mapping on magnetic resonance imaging (MRI). A high level of free water, not bound to glycosaminoglycans, within the cartilage leads to an increase in the T2 relaxation time [4]. These alterations in T2 relaxation time can be seen even before they become visible as cartilage damage in conventional T1, T2, or proton density (PD)-weighted sequences [5–8].

Changes to cartilage and the knee joint are common among young adults involved in competitive sports [9] and are due to factors such as trauma and repetitive stress associated with short-term overuse of the joints [10]. In the worst case, competitive sports lead to knee joint arthrosis [11]. A few studies have demonstrated the value of T2 mapping in the detection of early cartilage changes in the case of competitive sports such as ballet dance [12] and soccer [13]. A recent study on the menisci of adult female volleyball players in competitive sports was able to show changes in the menisci already in young adulthood with quantitative MRI (qMRI) T1 rho and T2* mapping, highlighting the relevance of early monitoring of adolescents in competitive sports [14]. No such studies are available for the pediatric group of volleyball players at a competitive level, where, depending on the player's position, long distances of more than 1.5 km are covered within a narrow space of the court, with many changes in direction and load, or high jumps are executed [15, 16]. In addition, volleyball is an impact sport in which repetitive and suprathreshold stresses are experienced, especially on the knee joints, due to numerous and great-altitude jumps: which may increase the likelihood of early degenerative processes.

Aim of the Study

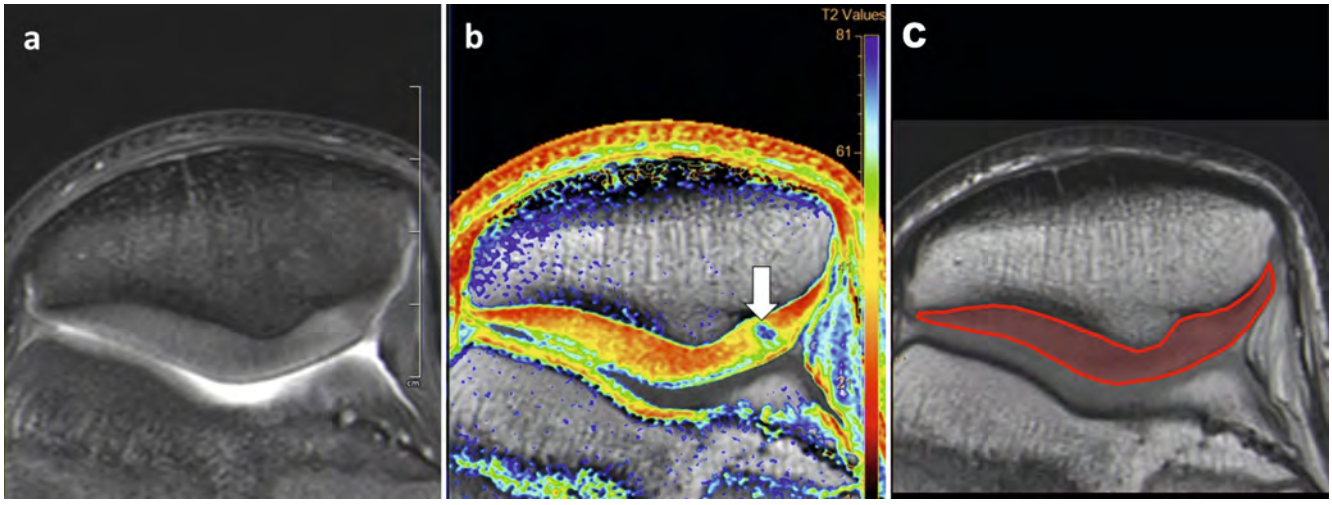
The aim of this study was to figure out whether subclinical cartilage damage is already detectable by T2 mapping on MRI among adolescents playing volleyball as a competitive sport.

Materials and Methods

A positive vote by the local ethics committee was received before the start of the study. Written informed consent was obtained from the participants or their legal representatives.

Screening and Preparation of Participants

Healthy male adolescents aged 12 to 17 years were enrolled for this prospective, monocenter study between March 2019 and May 2019. The exclusion criteria were history of surgeries, known previous orthopedic conditions, or lower extremity injuries in the last six months. The studied subjects had none of the above characteristics. The competitive athletes were defined as those who played volleyball for at least 3 years with more than 700 minutes



▶ **Fig. 1** Patellofemoral cartilage in a competitive volleyball athlete in **a** axial proton density with fat saturation (PD fs), **b** a T2 map, and **c** the measurement ROI. The focal cartilage alteration with increased T2 relaxation time (85 ms) in the medial facet (arrow), which is well delineated in the T2 map, is almost not visible in the PD fs.

▶ **Abb. 1** Retropatellarer Knorpel bei einem Volleyball-Leistungssportler in **a** einer axialen PD fs, **b** einer T2-Mapping-Karte und **c** die Mess-ROI: Die in der T2-Mapping-Karte gut abgrenzbare fokale Knorpelveränderung mit erhöhter T2-Relaxationszeit (85 ms) an der medialen Facette (Pfeil) ist in der PD fs nahezu nicht sichtbar.

of playing time per week. They were students at a sports school and together in one class with volleyball as the performance focus. Contact was made through the coach. The control subjects should not participate in any impact sport except at an age-average activity level. They were recruited via a longitudinal study of civilization diseases in childhood and adolescence. Both groups received an evaluation of their knee MRI examinations that was understandable for laypersons and a subsequent gait analysis with tips for optimizing movement as a motivation. The extent of sporting activity and non-sporting activity was estimated through the standardized Motor Module Questionnaire [17]. Acute or prolonged knee joint complaints as an exclusion criterion were determined through the modified standardized knee injury osteoarthritis outcome score questionnaire for children [18]. At the time of MRI, all the athletes had the same training status, i. e., the same number of training sessions or participation in competitions and at least 48 hours of time interval after the last training session in order to minimize acute load-induced effects on cartilage and bone marrow [19, 20]. Since hormonal status may affect cartilage maturation [21], only male subjects were included to keep the collective as homogeneous as possible.

Magnetic Resonance Imaging

All MRI examinations were performed on a Philips Ingenia 3 T MRI (Philips Medical Systems International BV, Best, the Netherlands) with a 16-channel knee coil. In each session, both knees of the subject were examined. For anatomic assessment, a PD turbo spin-echo (TSE) sequence with fat suppression (fs) in 3 planes (slice thickness 3 mm, echo time 35 ms, repetition time 2000 ms, and flip angle 90°) and a sagittal T1 TSE sequence (slice thickness 3 mm, echo time 10 ms, repetition time 573 ms, and flip angle 90°) were acquired. T2 mapping was acquired using multi-echo T2 TSE sequences with six echo trains each (echo times 13, 26, 39, 52, 65, and 78 ms, repetition time 2000 ms, and flip angle 90°) transversely over the patellofemoral cartilage. In addition, to simultaneously assess all four cartilage compartments (i. e., both femoral condyles and both cartilages of the tibial plateau), a coronal sequence was performed.

Evaluation

T2 mapping sequences were analyzed using the IntelliSpace Portal software (Philips, Best, The Netherlands). In the axial slices of the patellofemoral cartilage, one region of interest per slice was placed by hand over the entire cartilage visible in this slice (▶ **Fig. 1c**), and the T2 relaxation times (mean and maximum) were recorded and averaged. The measured value for the T2 relaxation time was displayed by the software in milliseconds (ms). A similar procedure was performed on the coronal slices of the articular cartilage, each separated according to the four compartments (medial femoral, lateral femoral, medial tibial, and lateral tibial) (▶ **Fig. 4c**). Focal cartilage changes were evaluated according to their location and geometry.

Statistics

Statistical analysis was performed with SPSS 27 (IBM Corp, Armonk, USA). Both knee joints of each subject were examined. Differences in central tendency were assessed with a two-tailed T-test or a Wilcoxon-Mann-Whitney test, depending on whether normal distribution was present in the Shapiro-Wilk test. Qualitative characteristics were evaluated independently by two experienced radiologists with 10 and 16 years of professional experience, respectively, and subjected to the chi-square test and Fisher exact test (for $n < 5$). Interrater reliability was determined using Cohen's kappa coefficient.

▶ **Table 1** Demographic parameters (statistical significance indicated by *).

	Controls (n = 15)		Volleyball players (n = 15)		*p*-value
	Median	Interquartile range (IQR)	Median	Interquartile range (IQR)	
Age (years)	16.0	16.1–14.8	16.1	17.1–15.1	*p* = .10
Weight (kg)	72.7	75.0–58.0	74.8	84.6–69.3	*p* = .13
BMI	21.0	23.6–18.4	21.4	22.6–19.8	*p* = .80
Height (cm)	178	184–171	187	193–184	*p* <.001*

Results

Participant Data

30 male adolescents (60 knee joints) with a median age of 16.1 years (IQR 17.0–15.1 years) participated in this study. 15 subjects were competitive athletes that played volleyball, and the other 15 subjects were controls without an increased activity level. The mean activity duration of the competitive athletes (everyday life, school, club sports, and leisure time) was 1518 minutes per week (mpw) in total. The mean activity of the control subjects was 851 mpw ($p = .02$). The group of competitive athletes is very homogeneous, as the group composition and training regime are constant for more than two years for all fifteen athletes. This includes seven training sessions per week (together about 940 mpw, each > 120 minutes per day (mpd)). A prevention program is completed twice per week to reduce the risk of trauma. The age distribution of the athletes is: mean 16.07 +/– 1.12 years, range 14–17 (14 years, n = 2; 15 years n = 3; 16 years n = 3; 17 years n = 7). The two groups differed from each other with respect to height, but not age, weight, and body mass index (BMI) (▶ **Table 1, 2**).

Patellofemoral cartilage

In 12 of 60 knee joints (5 competitive athletes, 1 control, $p = .01$), the transition of the medial to lateral facet of the patellofemoral cartilage showed areas with increased T2 relaxation times compared to the rest of the cartilage (▶ **Fig. 1b, 2** and ▶ **Table 3**). The normal gradient of T2 relaxation times from the cartilage-bone interface towards the articular surface [22] was abolished within the lesions. In each case, the changes affected both knee joints of the subjects symmetrically. Of the ten affected knees of five competitive athletes, eight belonged to four players who played the position of middle blocker (▶ **Fig. 3**) ($p = .10$). The interrater reliability was excellent, with a κ value of 1.0.

Femoral knee cartilage

In 19 of 60 knee joints (8 competitive athletes, 3 controls, $p < .05$), an increase in focal T2 relaxation time was found in the cartilage of the medial femoral condyle. Again, the zonal division of T2 times was abolished. The findings were sharply bordered bilaterally with respect to the surrounding cartilage and presented in anterior-posterior extension as elongated, band-like areas narrowing dorsally (▶ **Fig. 2, 4, 5** and ▶ **Table 3**). An association of the femoral knee cartilage lesions was seen in the remaining player positions. The interrater reliability was excellent with a κ value of 1.0.

Diffuse Cartilage Changes

Dividing the knee joint cartilage into four quadrants, the lateral femoral compartment showed the highest mean T2 times of 43 ms, followed by the medial femoral compartment with 40 ms. The medial and lateral tibial compartments showed the lowest T2 relaxation times at 34 ms and 33 ms, respectively. The only difference in mean T2 relaxation time between competitive athletes and controls was found in the medial femoral cartilage in the left knee (38.7 ms and 41.0 ms, respectively, $p < .05$; CI 95 %, -4.6–0 ms) (▶ **Fig. 6,** ▶ **Table 3**), with the athletes having shorter T2 times than the controls. In addition, the maximum T2 relaxation times of the competitive athletes exceeded those of the controls in the medial (97.6 ms and 91.6 ms, $p = .05$; CI 95 %, 0 ms – 11.9 ms) femoral covering cartilage on the left, and in the medial (100.8 ms and 91.1 ms, $p < .04$; CI 95 %, 0.8–17.6 ms) and lateral (101.7 ms and 94.1 ms, $p < .02$; CI 95 %, 1.6–13.5 ms) femoral covering cartilage on the right (▶ **Fig. 7,** ▶ **Table 3**).

Discussion

This is the first cross-sectional study to demonstrate early cartilage changes in adolescent competitive volleyball athletes using T2 mapping. There were more focal changes in the cartilage of the knee joint in the competitive athletes compared to those in a control population. Furthermore, the maximum T2 relaxation times were significantly higher in the athletes' medial femoral cartilage on both sides compared to the controls, which is discussed further below (▶ **Fig. 7**). The above-described findings could be the first signs of cartilage degeneration, possibly based on an overuse syndrome as described in young athletes [10]. In this case, tissue stress occurs with repetitive subclinical overload peaks whose temporal intervals are so short that the necessary regeneration time of the affected tissue is undercut. Thus, the cartilage changes could be interpreted as local reactions of the patellofemoral cartilage to frequently recurring, focal suprathreshold stress, for example, during the jumping and landing phases. This would also be supported by the fact that four of the five affected athletes in our study played as middle blockers, a posi-

▶ **Table 2** Demographic parameters per subject.

	Age	BMI	Weight (kg)	Height (cm)	Handedness: 1 right, 2 left
Volleyball players (n = 15)	17	21.32	73.3	185	1
	17	19.06	69.3	190	1
	16	24.42	92.2	194	1
	17	22.24	74.8	183	1
	17	21.53	79.8	192	1
	14	17.27	60.6	187	1
	16	21.38	88.1	203	2
	17	19.83	69.5	187	1
	17	20.28	75.7	193	1
	17	21.51	71	181	1
	16	17.83	62.4	187	2
	16	22.56	76.8	184	1
	16	22.71	84.6	193	1
	15	30.49	113.1	192	1
	14	20.27	64.6	178	2
Controls (n = 15)	15	23.18	75.1	180	1
	17	29.95	88.2	171	1
	15	18.41	53.4	170	1
	16	18.38	56.3	175	2
	14	19.28	63.8	1.82	2
	16	21.91	75	185	1
	14	16.97	45.3	163	1
	14	28.52	88.35	1.76	1
	15	19.77	63.9	180	1
	15	20.95	58	166	2
	15	21.47	72.7	184	1
	16	18.52	74.9	201	2
	17	18	64.1	188	1
	16	23.62	75	178	1
	14	23.74	72.7	175	1

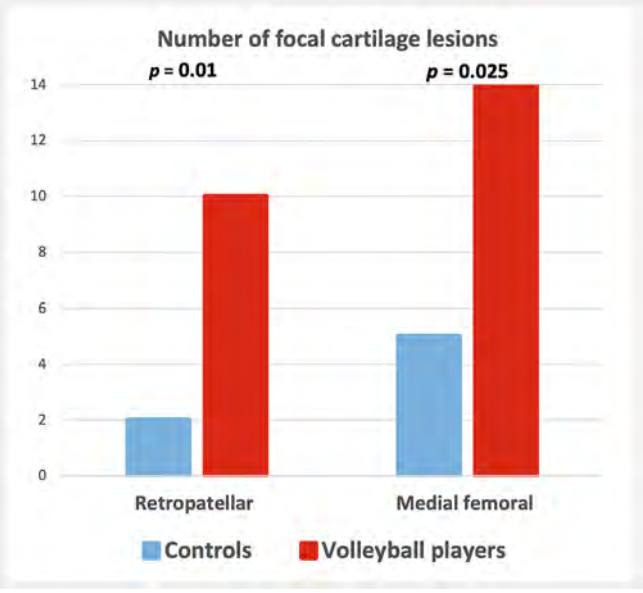
tion characterized by multiple high jumps [16]. The fact that the changes were laterally symmetrical, occurring on both knees, also speaks in favor of this.

Patellofemoral cartilage

Cartilage changes in our adolescent collective were almost not visible in the conventional sequences (PD-TSE fs and T1-TSE). This is consistent with a study by Boeth et al. in adolescent and adult volleyball players: while cartilage damage was observed in more than half of the adult volleyball players, no lesions were found in adolescents [15]. The higher percentage of cartilage damage in adult players in their study suggests that playing volleyball at a professional level predisposes athletes to cartilage damage. However, the early form of these changes, i. e., T2 relaxation time change, was not examined in the study, which may explain the lack of changes in the adolescents.

Apprich et al. highlight the high value of T2 mapping, especially in the early phase of cartilaginous degeneration of the patellofemoral cartilage [23]. They also address the issue of load distribution in the patellofemoral joint. During walking, the gliding motion leads to a diffuse load distribution rather than a point load distribution. However, the situation in the case of impact sports such as volleyball appears to be different as the patellofemoral cartilage is subjected to high physical loads. This is especially true for the transition from the medial to the lateral facet, as this zone is pressed against the femoral sulcus during jumps and is thus susceptible to degenerative changes. Liess et al. showed a

close temporal relationship between athletic stress and its effect on patellofemoral cartilage [24]. They reported a reduction in both cartilage thickness and T2 relaxation time immediately after 60 squats, which was reversed following a 45-minute rest, at which time an increase in both parameters was observed. The authors attributed this to a reabsorption of water into the matrix of the cartilage. Through histological studies with dogs that had to run 20 km per day for 15 weeks, Säämämen et al. showed that there was a significant increase in the cartilaginous water content in the femoropatellar groove, while the collagen content decreased [25]. These histomorphologic findings were interpreted as correlates of the initial cartilage degeneration. In humans, Kim et al. detected the highest T2 relaxation times in the middle third of the patellofemoral cartilage at the transition from the medial to lateral facet already under physiological conditions on axial MRI slices of the patella in adolescents [21]. This observation supports our findings that the first cartilage changes occurred here.



▶ **Fig. 2** Number of knees of volleyball athletes and controls with focal lesions of the covering patellofemoral and medial femoral cartilage. Both types of lesions are more common in volleyball players.

▶ **Abb. 2** Häufigkeit von fokalen Knorpelveränderungen retropatellar und medial femoral am Deckknorpel bei Knien von Volleyballern und Kontrollen. Beide Läsionen treten signifikant häufiger bei Volleyballern auf.

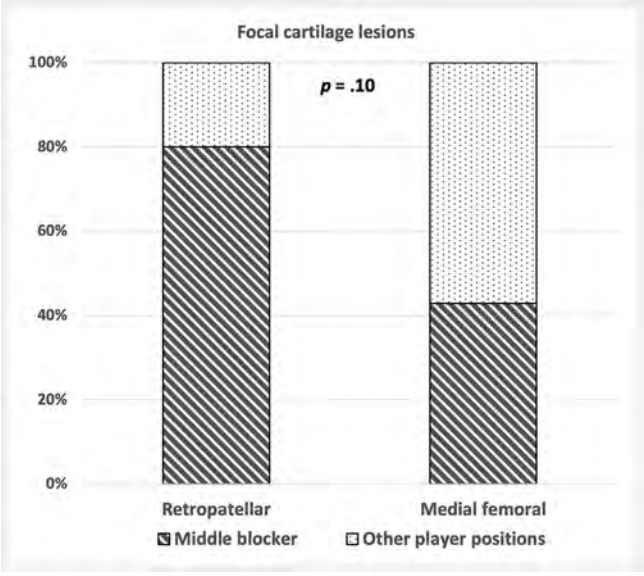
The relationship between increased physical activity and increased T2 relaxation times or focally increased cartilage water content is consistent with the findings of Stahl et al. and Stehling et al. [26, 27]. In an adult collective they showed on the one hand the relationship between greater T2 relaxation time, which has been diffusely detectable throughout the patellofemoral cartilage, and increased physical activity, and on the other hand also a relationship between activity and focally circumscribed cartilage changes. The knowledge of regional changes in T2 relaxation time is particularly important because the increase in the T2 relaxation time of cartilage precedes the cartilage damage detected several years later [7]. In addition, once focal signal enhancements of the cartilage become visible in standard MR sequences, they are very likely to develop into cartilage defects [8].

Covering cartilage

Lesions on the covering cartilage of the medial femoral condyle in our competitive sports collective occurred predominantly not in athletes who played the position of middle blocker, but rather in the running-intensive positions, i. e., outside attacker, setter, and the libero. These positions are characterized by substantial running of over 1.5 km with abrupt changes in direction and load in a confined space [16]. The predisposition to the medial femoral compartment can be explained by the course of the main load axis of the body through this structure. Due to the high biomecha-

▶ **Table 3** Local distribution of T2 relaxation times (ms) and focal lesions.

Cartilage location		Volleyball players		Controls	
		T2-values (ms) mean/max.	Number of focal lesions	T2-values (ms) mean/max.	Number of focal lesions
Left	Femoral media	38.7/97.6	8	41.0/91.6	3
	Femoral lateral	42.7/94.5	0	43.4/90.4	0
	Tibial medial	31.3/88.0	0	32.7/87.5	0
	Tibial lateral	33.3/89.2	0	34.0/88.9	0
	Patellofemoral	37.0/93.4	5	36.9/86.3	1
Right	Femoral media	40.6/100.1	6	41.1/90.1	2
	Femoral lateral	42.8/101.7	0	44.3/94.2	0
	Tibial medial	35.6/98.9	0	35.7/94.1	0
	Tibial lateral	31.6/93.6	0	32.2/94.2	0
	Patellofemoral	38.0/94.9	5	37.6/87.4	1

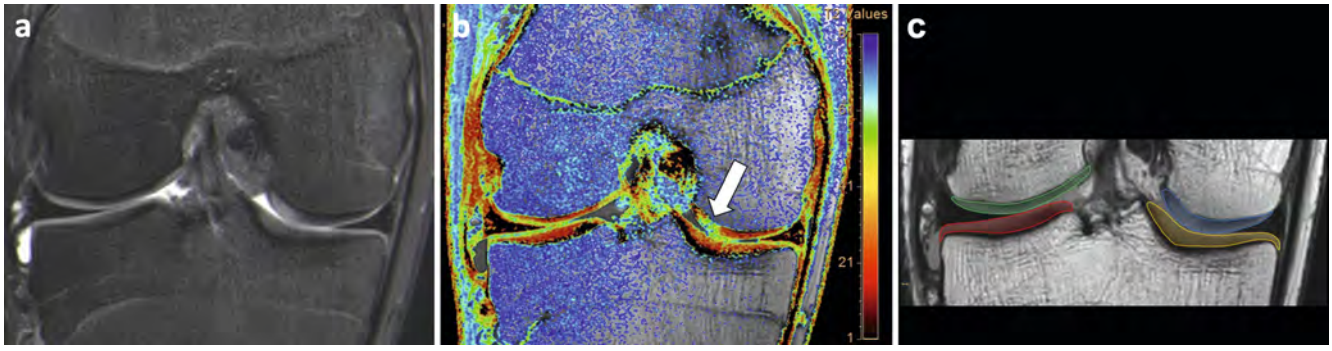


▶ **Fig. 3** Percentage frequency of focal cartilage changes of the patellofemoral and medial femoral cartilage in knees of volleyball players of different player positions. Middle blockers standing at the net show greater changes in the patellofemoral articular cartilage than players in the other player positions, whereas in the latter group more changes are observed in the medial femoral covering cartilage.

▶ **Abb. 3** Prozentuale Häufigkeit des Auftretens fokaler Knorpelveränderungen retropatellar und medial femoral am Deckknorpel in Knien von Volleyballern in Abhängigkeit von der Spielerposition. Am Netz stehende Mittelblocker zeigen mehr Veränderungen am retropatellaren Knorpel als die übrigen Spielerpositionen, wohingegen bei Letzteren die Befunde am Deckknorpel medial femoral überwogen.

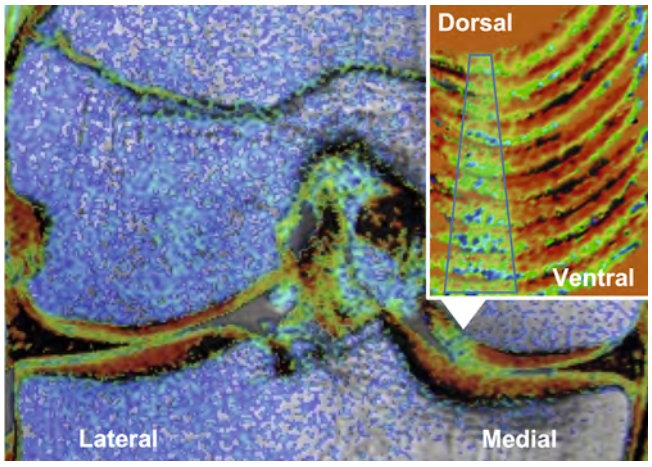
nical forces there, changes in T2 mapping and later cartilage degeneration can occur at an early stage [13, 28].

The mean T2 relaxation times of the four compartments of the femorotibial joint (medial femoral, lateral femoral, medial tibial, and lateral tibial) showed a typical distribution pattern of T2 relaxation times, consistent with the literature for the pediatric [29] and the adult population [30], with the femoral being the highest and the tibial being the lowest. The mean T2 relaxation times differed between competitive athletes and controls only for the left medial femur and were lower in the athletes. This contradicts other recent studies in young adults, where the T2 relaxation times were higher. There could be two reasons for this: firstly, better muscular stabilization of the knee joint with resulting relief of the cartilage. All subjects of the study received a gait analysis after the MR examination [31]. The competitive athletes maintained a largely neutral leg axis compared to the controls even during strong loads, such as the counter movement jump, which indicates ideal physiological loading of all cartilage compartments. Secondly, despite being the same median age, the adolescent volleyball players were taller. This suggests that they were already ahead in their skeletal development compared to the controls, which in turn would explain the lower mean T2 values. These values decrease continuously from childhood to young adulthood with increasing skeletal maturity [21, 29]. The maximum T2 relaxation times were significantly increased in both medial femoral compartments of the athletes but not the mean T2 relaxation times. This could be due to the fact that the band-like focal lesions with increased T2 relaxation times (> 80 ms) described above cross the sectional planes perpendicularly. As this affects the total ROI in the coronal plane only to a small



▶ **Fig. 4** Coronal **a** PD fs and **b** T2 mapping images of the knee of a volleyball player with focally increased T2 relaxation time in the covering cartilage of the medial femoral condyle (arrow). The finding is almost not visible in PD fs. **c** The four measurement ROIs per coronal slice: green – femoral lateral; blue – femoral medial; red – tibial lateral and yellow – tibial medial. Measurements were taken in each slice from ventral to dorsal as long as articular cartilage was visible.

▶ **Abb. 4** Koronare **a** PD fs und **b** T2-Mapping-Bilder des Knies eines Volleyballers mit fokal erhöhter T2-Relaxationszeit im Deckknorpel der medialen Femurkondyle (Pfeil). Der Befund ist in der konventionellen Sequenz nahezu nicht sichtbar. **c** Die 4 Mess- ROIs pro coronarer Schicht: grün – femoral lateral; blau – femoral medial; rot – tibial lateral und gelb – tibial medial. Die Messungen wurden in jeder Schicht von ventral nach dorsal durchgeführt, solange Deckknorpel sichtbar war.



▶ **Fig. 5** Zoomed version of T2 mapping image of the knee of a volleyball player with focally increased T2 relaxation time in the covering cartilage of the medial femoral condyle. The focally increased T2 relaxation time extends in a band-like fashion over the cartilage of the entire condyle. It is wider ventrally and narrower dorsally (arrowhead).

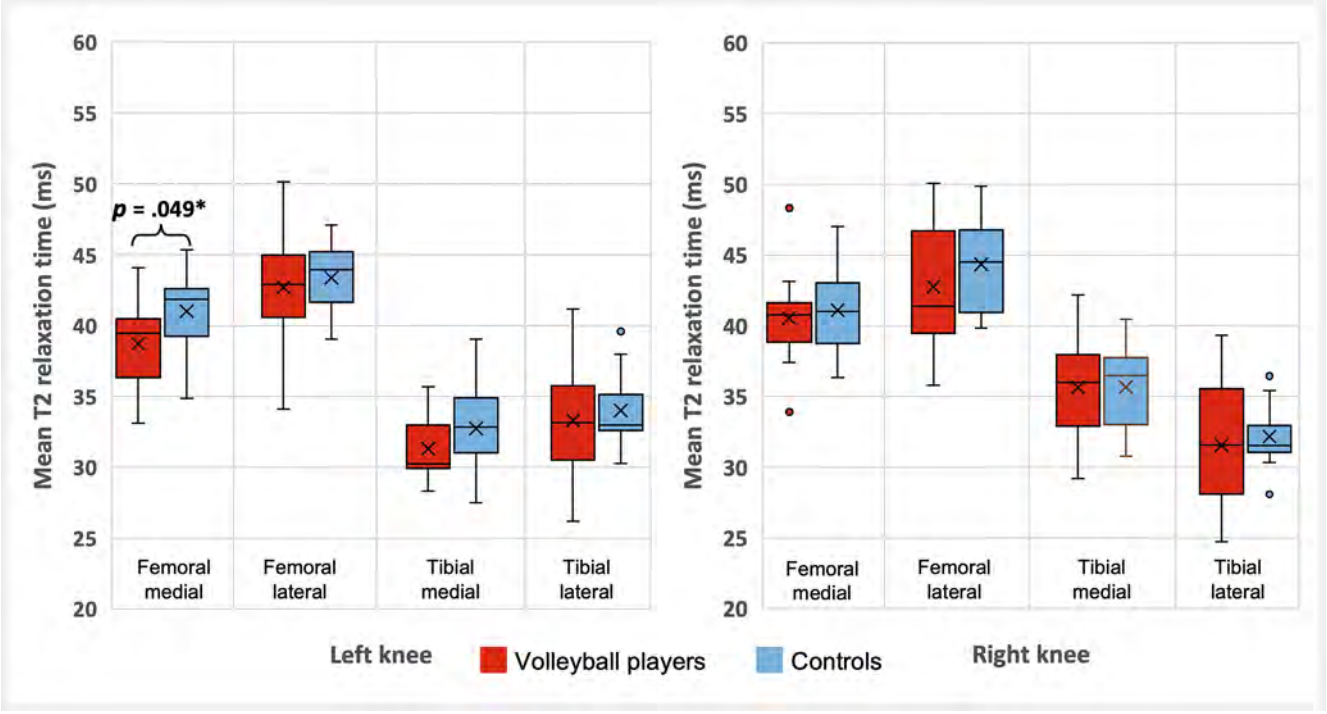
▶ **Abb. 5** Der Befund erstreckt sich im T2-Mapping bandförmig über den Deckknorpel der gesamten medialen Femurkondyle und ist ventral breiter um nach dorsal schmaler zu werden (Pfeilspitze).

extent, the mean T2 relaxation times do not respond to the focal changes, but the maximum T2 relaxation times. A smaller layout of the ROIs might solve this issue, but also leads to less stable measurements. Perifocally around the center of the lesions, a zone with likewise increased T2 relaxation times was seen, although it was less severe than in the center. The latter could be an early diffuse cartilage response to athletic loading, which could be interpreted as a first sign of incipient alteration of the complex cartilage matrix [5, 6]. This hypothesis is also supported by the finding of Kretschmar et al. that in addition to focal changes, diffuse changes in cartilage precede later cartilage damage, sometimes by several years [32]. To prevent this sequence from preclinical to clinical cartilage changes in competitive volleyball athletes, prevention programs, such as "The 11" which already exists for amateur soccer players [33], could be useful.

Limitations

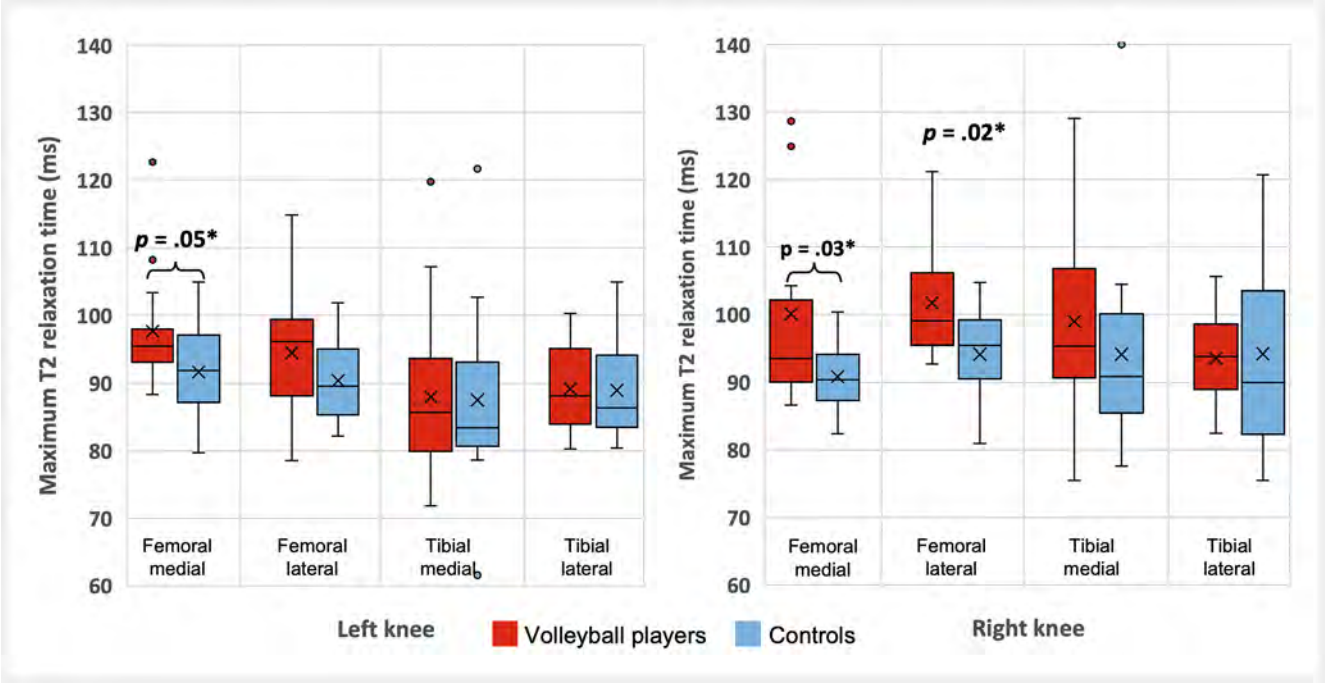
We acknowledge that our study has a few possible limitations:

1. The two groups differed significantly in terms of height, but not in terms of weight and especially BMI. The T2 relaxation time is codependent on BMI [30]. Yet, since in our study the BMIs of the two groups did not differ significantly, this factor is unlikely to skew the results.



▶ **Fig. 6** Comparison of the mean values of the T2 relaxation times of the covering cartilage between volleyball players (red) and controls (blue), separated according to the four compartments (femoral medial, femoral lateral, tibial medial, and tibial lateral). Differences were only found on the left medial femur.

▶ **Abb. 6** Vergleich der Mittelwerte der T2-Relaxationszeiten (in ms) des Deckknorpels zwischen Volleyballern (rot) und Kontrollen (blau) getrennt nach den 4 Kompartimenten (femoral medial, femoral lateral, tibial medial und tibial lateral). Signifikante Unterschiede ergaben sich medial femoral.



▶ **Fig. 7** Comparison of the maximum values of the T2 relaxation times of the covering cartilage between volleyball players (red) and controls (blue), separated according to the four compartments (femoral medial, femoral lateral, tibial medial, and tibial lateral). Significant differences were found on both sides in the medial femoral compartment and additionally femoral lateral on the right side with an increase in T2 times in the volleyball players in the compartments through which the main load-bearing axis runs.

▶ **Abb. 7** Vergleich der Maximalwerte der T2-Relaxationszeiten (in ms) des Deckknorpels zwischen Volleyballern (rot) und Kontrollen (blau) getrennt nach den 4 Kompartimenten (femoral medial, femoral lateral, tibial medial und tibial lateral). Signifikante Unterschiede ergaben sich bds. jeweils im medial femoralen Kompartiment und femoral lateral rechts mit einer Erhöhung der T2-Zeiten bei den Volleyballern in den Kompartimenten, durch die die Haupttraglastachse verläuft.

2. The results of our male cohorts cannot readily be applied to female adolescents. For example, female volleyball players often have more valgus of the leg axis during landing [34], so their medial femorotibial joint may be less loaded than is the case in male adolescents. Furthermore, there is a close correlation between gender, age, and the T2 relaxation time of the knee joint cartilage [21].
3. It is a small number of cases, with limited significance for the overall population. In order not to compromise the homogeneity of the group of competitive athletes, an entire volleyball class with fifteen pupils at a sports school was studied. This ensures equal training levels, equal distances to competitions, and the support of the coach. An enlargement of the group with test subjects from other cities would have affected these identical conditions. Therefore, the number of subjects could not be increased arbitrarily.

Conclusion

In adolescent volleyball players in competitive sports, early cartilage lesions are detectable by T2 mapping in both patellofemoral and medial femoral cartilages, with the distribution of lesions depending on player position.

Since the cascade from T2 relaxation time increase to conspicuous cartilage damage is well established, an early counter-regulation (e. g., through an adapted training profile, targeted physiotherapy, and appropriate muscle building training) could possibly prevent later damage. To allow wide availability of the method to as many athletes as possible, the well-established method of T2 mapping was used in this study to assess knee cartilage.

CLINICAL RELEVANCE OF THE STUDY

1. Since the progression from initial diffuse or focal T2 relaxation time increases of knee joint cartilage to cartilage damage and subsequent osteoarthritis is well documented, early counter-regulation, e. g., through an adapted training profile, targeted physiotherapy, and appropriate muscle building training, could possibly prevent later cartilage damage.
2. The results show that training should be accompanied by medical monitoring even in adolescents who are active at a competitive sport level.
3. For this purpose, T2 mapping is well suited as a widely available, well-established and robust MRI examination method.

KLINISCHE RELEVANZ DER STUDIE

1. Da die Entwicklung von initial diffusen oder fokalen T2-Relaxationszeiterhöhungen des Kniegelenkknorpels hin zu manifesten Knorpelschäden und nachfolgender Arthrose gut belegt ist, könnte eine frühe Gegenregulation z. B. durch ein angepasstes Trainingsprofil, gezielte Physiotherapie und entsprechendes Muskelaufbautraining eventuell spätere Knorpelschäden verhindern.
2. Die Ergebnisse zeigen, dass auch Jugendliche, die auf Leistungssportniveau aktiv sind, eine trainingsbegleitende medizinische Überwachung erhalten sollten.
3. Zu diesem Zweck ist das T2-Mapping als breitflächig verfügbare, gut etablierte und robuste Untersuchungsmethode im MRT gut geeignet.

Conflict of Interest

The authors declare that they have no conflict of interest.

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