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Ultrasound-guided determination demonstrates influence of age, sex and type of sport on medial femoral condyle cartilage thickness in children and adolescents

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Abstract

Purpose: To analyse the reliability of ultrasound-guided measurement of the cartilage thickness at the medial femoral condyle in athletically active children and adolescents before and after mechanical load in relation to age, sex and type of sport.

Methods: Three successive measurements were performed in 157 participants (median/min–max age: 13.1/6.0–18.0 years, 106 males) before and after mechanical load by squats at the same site of the medial femoral condyle by defined transducer positioning. Test–retest reliability was examined using Cronbach's α calculation. Differences in cartilage thickness were analysed with respect to age, sex and type of practiced sports, respectively.

Results: Excellent reliability was achieved both before and after mechanical load by 30 squats with a median cartilage thickness of 1.9 mm (range: 0.5–4.8 mm) before and 1.9 mm (0.4–4.6 mm) after mechanical load. Male cartilages were thicker ($p < 0.01$) before (median: 2.0 mm) and after (2.0 mm) load when compared to female cartilage (before: 1.6 mm; after: 1.7 mm). Median cartilage thickness was about three times higher in karate athletes (before: 2.3 mm; after: 2.4 mm) than in sports shooters (0.7; 0.7 mm). Cartilage thickness in track and field athletes, handball players and soccer players were found to lay in-between. Sport type related thickness changes after mechanical load were not significant.

Conclusion: Medial femoral condyle cartilage thickness in childhood correlates with age, sex and practiced type of sports. Ultrasound is a reliable and simple, pain-free approach to evaluate the cartilage thickness in children and adolescents.

Abbreviations: DEGUM, German Society of Ultrasound in Medicine (Deutsche Gesellschaft für Ultraschall in der Medizin); f, female; JIA, juvenile idiopathic arthritis; m, male; MRI, magnetic resonance imaging; MSUS, musculoskeletal ultrasound; MW, Mann–Whitney test; OA, osteoarthritis; prop., proportion; pt, paired *t* test; W, Wilcoxon paired sums test.

Level of Evidence: Level III.

KEYWORDS
cartilage, children, femoral condyle, musculoskeletal ultrasound, physical activity, sonography

INTRODUCTION

Knee osteoarthritis (OA) is a degenerative disease resulting in restricted mobility and chronic pain. Epidemiological data vary depending on the particular study designs. Due to demographic changes and owing to the ageing population, (knee) OA has become one of the most common diseases in industrialised countries [16, 43], representing an economic burden for health care and social systems [22, 23, 31, 34, 53]. In Global North nations such as the United States, the prevalence of knee OA has doubled over the last century [49]. The mechanisms behind the development of knee OA are an on-going subject of research. It is discussed controversially from representing a solely cartilage-limited to a multifactorial disease that affects the whole joint.

Influencing factors with an increased impact on the development of OA as, obesity, lack of exercise, inappropriate exercise and repetitive, mechanical stress are well described [33, 54]. Most often only symptoms of OA are treated until end-stage progression, resulting in knee and/or hip replacements. The acknowledgement as a multifactorial disease should therefore result in earlier comprehensive and prevention strategies for OA therapies.

Optimal transmission of forces to the cartilage requires high compressive and low tensile strength. Excessive mechanical stress due to chronically incorrect, excessive overload and traumatic disturbances are significant triggers of cartilage degradation [17, 18]. Damage to articular cartilage plays a key role in the development of knee OA and related diseases. The impact of mechanical stress and physical activity on the thickness and volume of cartilage has been subject of research for decades [3, 9, 15, 20, 29, 38, 47]. The effect and influence of sex, growth, weight and body composition on the thickness of the articular cartilage in school-aged children has been reported in several studies [12, 19, 30, 41].

Nevertheless, data is scarce, especially on the modulation of cartilage thickness through physical activity. With respect to children and adolescents, it is unclear whether there is an influence of physical activity on the thickness of cartilage. Still, it cannot be ruled out that the appearance of clinical OA has its origins in childhood. Physical activity has undoubtedly numerous important and far-reaching health benefits when initiated early in life. However, it is largely unknown how specific movement patterns occurring in particular types of sport might impact on the composition and morphology of juvenile weight-bearing joints.

Ultrasound is an effective method to evaluate cartilage in children and adolescence. In particular, musculoskeletal ultrasound (MSUS) is an imaging technique that can be used to diagnose, monitor, and control the therapeutic response in paediatric inflammatory rheumatic diseases, especially in juvenile idiopathic arthritis (JIA) [5, 45, 46, 51]. Overall MSUS is a well-accepted, easily accessible, nonirradiating and inexpensive imaging technique to evaluate early changes on the developing cartilage, allowing dynamic examination of several joints during the same session.

The aim of the present study is to evaluate the effect of moderate to intensive sport activities on the knee cartilage of children and adolescents by measuring medial femoral condyle cartilage thickness via ultrasound before and after physical exercise/mechanical loading. Reliability tests are performed evaluating the accuracy of the method, especially in cartilage defects of children and adolescents. The relationship of age, sex and type of sport on the thickness of the articular cartilage in children and adolescents, as well as the changes in the compressibility of the cartilage following short-term mechanical loading were assessed.

MATERIALS AND METHODS

Study design and participants demographics

This study was designed as an exploratory cross-sectional study, conducted between February 2022 and November 2022, and approved by the Ethics Committee of Saarland (file number 191/19). All participants were physically active children and adolescents who regularly participate in various sports including soccer, handball, karate, track and field and shooting sports (competitive or club sports). Participants and their legal guardians were informed about the background and necessity of the study, the procedure and the rights of participants. Exclusion criteria were absence of informed consent of the participant or legal guardian, current, unresolved symptoms of the lower extremity and/or known cartilage pathologies; malposition or paralysis of the lower extremities; attention deficit or hyperactivity disorder. Written consent was obtained from 160 children and adolescents and their legal guardians before the study.

One-hundred and fifty-seven participants were included for further analysis into the study, three participants were excluded for formal reasons. Sex was distributed in favour for males (males: 106 participants = 67.5%; females: 51 participants = 32.5%). Median age was 13.1 years (males: 13.2 years; females: 12.9 years). Study participants comprised 54 handball players, 45 karate fighters, 40 soccer players, 10 sport shooters and eight track and field athletes. More detailed demographic data of the study population are shown in Figure 1 and Table 1.

The thickness of the medial femoral condyle cartilage in children and adolescents was assessed by ultrasound before and after exposure to mechanical loading. After the initial sonographic assessment, study participants were asked to perform 30 squats followed by immediate further cartilage thickness assessment. Comparisons were made for differences in age, sex and type of sport executed.

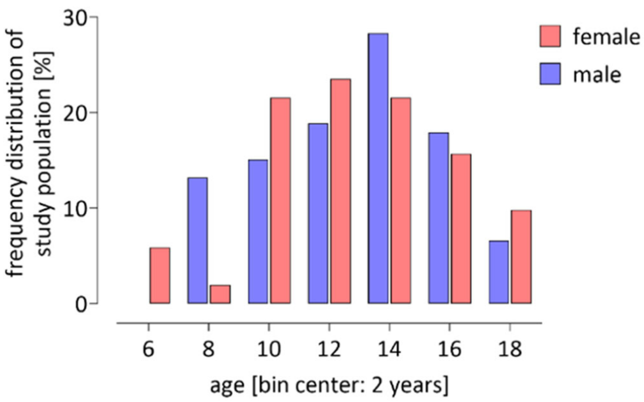

FIGURE 1 Relative age fractions of female (red) and male (blue) participants. Continuously collected ages were clustered into bins of 2 years for clarity. Normality test (Shapiro–Wilk test) showed normal distribution for females, but not for males.

Data acquisition

A *Clarius L7 BW Scanner*, Colour and Power Doppler sonography device (Clarius Mobile Health Corp.) was used for data collection. Operating at a frequency of up to 13 MHz, it achieves a maximum scanning depth of 7 cm. Measurement accuracy for lateral and axial distance was specified as follows: relative error ± 2%, minimum range 0.2 mm. All examinations and measurements were performed in the B-mode.

The device establishes a wireless, reliable connection using Bluetooth to an iPad (seventh generation) running iPadOS 16.1.1 (Apple Inc.). It offers cloud storage as well as internal storage. A second-generation Apple Pencil was used to mark the cartilage dimensions.

The participants sat down in a long seat on a treatment bench with their knee bent to the maximum of the dominant leg. Following the Suprapatellar Transverse Section, the transducer position was rotated horizontally by 90°, thus modifying the standard plane. For the determination of the cartilage thickness, the transducer was placed on the knee joint at a 90° angle coming from the adductor tubercle in a linear direction (Figure 2). Thereby, the transducer rests on the edge of the patella, which serves as a reference point and ensures consistent measurements for each individual. Given a smooth cartilage cover of a healthy knee joint, only minor, negligible deviations in the measured values are to

TABLE 1 Study population demographics.

Sport	Males (m)		Females (f)		Total	
	Participants (*n*; prop. m/sport)	Age (years)	Participants (*n*; prop. f/sport)	Age (years)	Participants (*n*; prop./study population)	Age (years)
Handball	35; 64.8%	13.1 (8.2–17.4)	19; 35.2%	14.5 (10.7–18.0)	54; 34.4%	13.2 (8.2–18.0)
Karate	28; 62.2%	10.3 (7.1–17.3)	17; 37.8%	10.9 (6.0–16.1)	45; 28.7%	10.8 (6.0–17.3)
Soccer	38; 95.0%	13.6 (10.8–16.9)	2; 5.0%	13.5 (13.2–13.8)	40; 25.5%	13.6 (10.8–16.9)
Shooters	5; 50.0%	15.1 (14.5–16.9)	5; 50.0%	15.4 (14.8–16.6)	10; 6.4%	15.3 (14.5–16.9)
Track and field	0; 0.0%	n/a	8; 100%	11.3 (10.6–13.9)	8; 5.1%	11.3 (10.6–13.9)
Total	106; 67.5%	13.2 (7.1–17.4)	51; 32.5%	12.9 (6.0–18.0)	157; 100%	13.1 (6.0–18.0)

Note: The columns 'males' (m) and 'females' (f) each show the absolute numbers of participants (*n*) as well as the relative proportions (prop.) of sex in the type of sport. 'Total' shows, in addition to the absolute numbers of participants (m + f), the relative proportions of the sport in the total study population. Ages are shown in median (min–max).

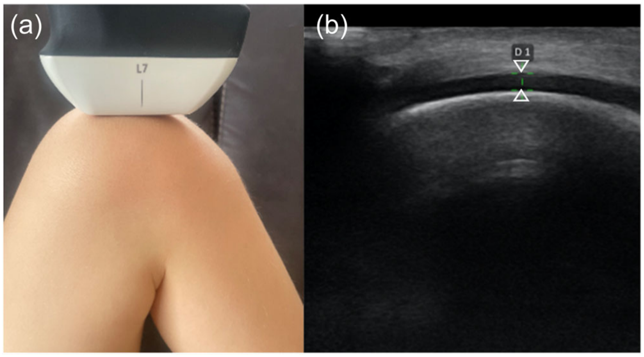

FIGURE 2 Imaging methodology of the medial femoral condyle cartilage. (a) Clarius L7 BW Scanner transducer position on the dominant leg. (b) Ultrasound image of the medial femoral condyle cartilage in adolescents. Arrowheads mark measurement points for thickness determination.

be expected, as only a varying width of the adductor tubercle could marginally influence the transducer position between individuals.

Cartilage thickness of the medial femoral condyle was measured three times in succession, followed by mechanic load to the joint (30 squats without supplemental weight). After completion, cartilage thickness of the medial femoral condyle was reassessed three times. Threefold serial measurements of all 157 participants before and after squats were used for the subsequent reliability test and analysis. Test–retest reliability to characterise the degree of variation in replicate measurements was chosen since the following criteria were true: all replicate measurements were taken with the same instrument on the same participants under the same conditions; single investigator study design.

Statistical analysis

A total sample size of 111 was calculated to be necessary for rejection of null hypothesis of equal means between five sport groups (effect size $f = 0.4$; power = 0.8; α error probability = 0.05) using G*Power 3.1.9 (Franz Faul and colleagues, Kiel University). Final sample size was increased compared to calculation to take account of the partially exploratory nature of the study. For reliability analysis, IBM SPSS Statistics for Macintosh, version 27.0. (IBM Corp.) was used. Test–retest reliability was assessed by Cronbach's α calculation. Three different calculations were performed with omission of one item each. The results of item calculations were summarised and displayed as a correlation value. Assessment of reliability was carried out as follows: Cronbach's $\alpha < 0.59$: poor; 0.60–0.69: questionable; 0.70–0.79: acceptable; 0.80–0.89: good; 0.90–0.95: excellent, <0.95: possibly unnecessary items.

All other statistical analysis were performed using GraphPad Prism version 10.0.2 for Windows (GraphPad Software). An average was calculated out of the three serial measurements for further analysis. Continuous data were expressed as median and range, and categorical data were expressed as absolute (n) and relative frequencies (±). Normal distribution was assessed by Shapiro–Wilk test. For metrically scaled characteristics, differences between two independent groups were tested with an unpaired t test, and for nonnormally distributed values, with a Mann–Whitney test. For dependent samples, a paired t test (with a given normal distribution) or a Wilcoxon matched-pairs signed sum test was used. For more than two independent groups (type of sport played), the Kruskal–Wallis test was used, followed by Dunn's multiple comparison test. Age-dependent correlations were calculated by Spearman correlation coefficient r. In all cases, a two-sided p value was compared against a 5% significance level.

RESULTS

Reliability assessment of the method

After calculating Cronbach's α from the data of all 157 participants, a perfect intrasession reliability of approx. 0.99 (both before and after the squats) was achieved (Table 2).

Variation in the thickness of the medial articular cartilage among the practiced type of sport

The assessed cartilage thickness ranged from 0.4 to 5.0 mm. Median cartilage thickness by sport ranked in descending order as follows: karate, track and field, handball, soccer, sport shooters. No statistically significant differences were found in cartilage thickness before and after performing 30 squats. While on a percentage level and grouped by sport, the median change was at most −6.2% (shooters), on an individual basis, the thickness changes after mechanical load of the knee joints were very heterogeneous and diametrically different (Figure 3).

Significant differences in the cartilage thickness were found between sports groups (Figure 4a). For example, before the squats, the sport shooters had significantly lower cartilage thicknesses compared to all other sport groups. Furthermore, before squats, the cartilages of the karate group were

TABLE 2 Intrasessional reliability of ultrasound-guided cartilage thickness determination at the medial femoral condyle.

Item (i.e., measurement)	Scale mean if item is deleted	Scale variance if item is deleted	Corrected item-scale correlation	Cronbach's α if item is deleted
Measuring session before squats				
Pre 1	4.13	3.11	0.98	0.99
Pre 2	4.14	3.09	0.99	0.99
Pre 3	4.15	3.08	0.98	0.99
Measuring session after squats				
Post 1	4.17	2.93	0.97	0.99
Post 2	4.16	2.96	0.99	0.98
Post 3	4.17	2.95	0.99	0.99

Note: The three repetitive measurements are marked as pre 1–3 (before 30 squats) and post 1–3 (after 30 squats).

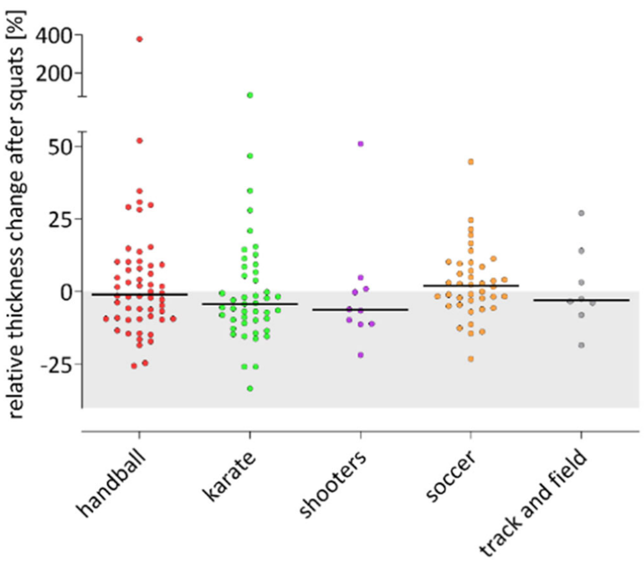

FIGURE 3 Relative change in thickness of medial femoral condyle cartilage after performing 30 squats by sport. Lines show the median, the grey-shaded area frames data points in the negative range.

thicker compared to those of soccer players. Test results after performing squats showed similar results (Figure 4b).

Sex-dependent variation in the thickness of the medial articular cartilage

A sex-dependent difference in cartilage thickness was observed, with higher median values in boys ($p < 0.002$ each, Table 3). No significant changes in cartilage thickness due to mechanical were measured in either girls or boys.

Age-dependent variation in the thickness of the medial articular cartilage

A significant correlation ($p > 0.0001$) with the age was observed for both, girls ($r = -0.82$; 95% confidence interval: −0.89 to −0.70) and boys ($r = -0.66$; 95% confidence interval: −0.76 to −0.53). Interestingly, cartilage thickness decreased from 6 to 18 years (Figure 5).

DISCUSSION

This study was conducted using ultrasound to measure the cartilage thickness of the medial femoral condyle. The approach of ultrasound-guided examination adopted for the present study was first described by Schmitz et al. [35]. They used ultrasound-guided examination as matched controls for comparison with the cartilage thickness measured by magnetic resonance imaging (MRI). In a first step, reliability of the ultrasound-guided approach for measuring the medial femur cartilage thickness was evaluated, since reliability of a diagnostic tool must be confirmed before its use in practice [21]. According to Cortina [6], reliability assessment should be interpreted as follows: Cronbach's α < 0.59: poor; 0.60–0.69: questionable; 0.70–0.79: acceptable; 0.80–0.89: good; 0.90–0.95: excellent, >0.95: possibly unnecessary items. A more general rule of thumb indicates that a reliability >0.8 is considered high [8]. Reliability within the measurements of the present study was 0.99, hence accurate determination of cartilage thickness at the medial femoral condyle was given.

Due to precisely predefined transducer positioning, it was possible to repetitively examine the same

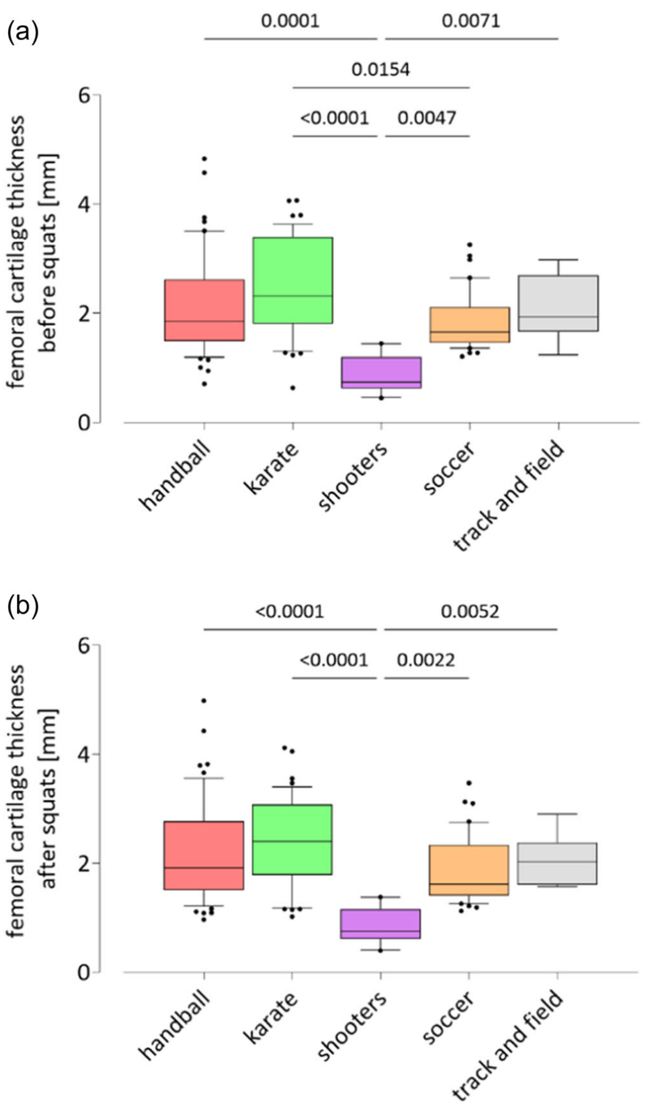

FIGURE 4 Cartilage thicknesses at the medial femoral condyle were significantly lower in sport shooters. (a) Cartilage thickness before performing 30 squats. (b) Cartilage thickness after performing 30 squats. Values above the plots show adjusted p values (Kruskal–Wallis test + post hoc Dunn's) below the significance level ($\alpha = 0.05$).

location, which was easy to scan when the leg was bent maximally. The ultrasound examination was performed in a slightly modified scanning plane (Suprapatellar Transverse Section) compared to the plane predefined by the German Society of Ultrasound in Medicine (Deutsche Gesellschaft für Ultraschall in der Medizin) [13]. This modification provided the advantage that the entire transducer could be placed parallel to the patella ensuring the same stop on every measurement. In addition, high image resolution enabled to mark cartilage boundaries precisely.

Following reliability assessment, the main objective was to investigate the cartilage thickness at the medial femoral condyle before and after mechanical loading in physically active children and adolescents. It was aimed to analyse how age and sex as well as different sporting activities affect cartilage thickness and potentially the health of the knee joint. Previous publications are mostly based on very specific questions and/or small numbers of subjects and were often performed

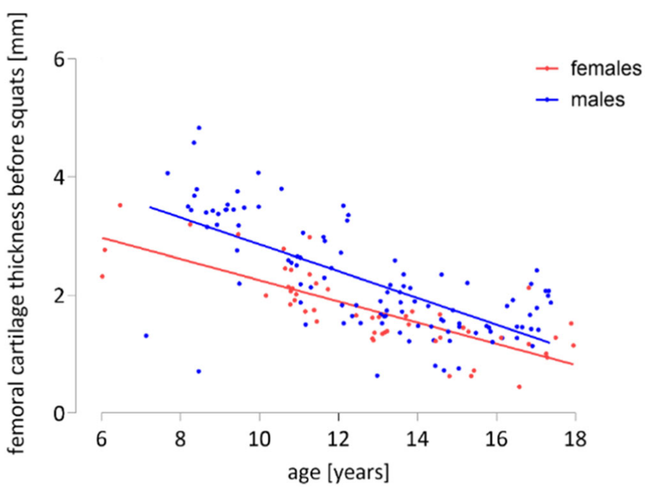

FIGURE 5 Correlation between age and medial femoral condyle cartilage thickness. Red data points and regression line: females; blue data points and regression line: males.

TABLE 3 Female participants had significant lower cartilage thicknesses at the medial femoral condyle compared to male participants.

	Males	Females	p Value m vs. f
Cartilage thickness (mm) before squats	2.02 (0.63–4.83)	1.64 (0.45–3.51)	0.0019 (MW)
Cartilage thickness (mm) after squats	2.04 (0.67–4.98)	1.65 (0.40–3.20)	0.0008 (MW)
p Value before vs. after squats	n.s. (W)	n.s. (pt)	

Note: Data are shown in median (min–max). No change was seen before and after squats in both sexes (m = males, f = females). Following testing for normal distribution by Shapiro–Wilk test, nonparametric MW was used for the independent variables and either parametric paired t test (pt) or nonparametric Wilcoxon paired sums test (W) was used for the dependent variables.

Abbreviations: MW, Mann–Whitney test; n.s., not significant.

on adults. One of the few comparable MRI-based studies on 20 adolescent (between 15 and 17 years) and 20 mature volleyball athletes (between 40 and 65 years) found that there was a significant annual increase in patellar and trochlear cartilage thickness in young athletes, whereas the opposite trend was seen in mature athletes [7]. In the present study with 157 children and adolescents, the thickness of the medial femur condyle differed significantly within the different sport groups. Active participation of the study collective in certain sports clubs made it possible to assign data to individual types of sport. In children and adolescents performing karate, median values were three times higher than in sport shooters. We suspect an association of divergent loading of the knee joint related to the two different types of sport. Babayeva et al. could demonstrate that within a male, young adult study population, athletes (volleyball players, soccer players, basketball players and weightlifters) showed significantly thicker femoral cartilage than a sedentary control group [1]. Positive effects on cartilage thickness observed were limited to sports that exert a constant, varying load on the knee, whereas sports shooters hold a more static leg position. Although mechanistic reasons and causalities were not tested in this study, these data may indicate that sport-specific movement patterns during growth affect articular cartilage formation in different ways. Similarities can be found in animal models and exercise recommendations for bone health. It is well known that static, low compressive load suppresses bone formation, which is why dynamic loading techniques of the extremities are preferred in mechanical loading studies on mouse and rat models [27, 32]. Dynamic resistance training can increase bone mineral density in postmenopausal women [37] and is, therefore, recommended to improve bone health.

To obtain an overview of cartilage thickness development throughout children and adolescents, a wide range of different age groups was included. Thus, data from participants aged 6 to 18 years could be analysed providing a good insight into age progression per sex. Knee cartilage was significantly thicker in boys than in girls, which is in general agreement to previous studies in adults [4, 11]. The thickness measured at the medial femoral condyle displayed a slight decrease in children with increasing age. In contrast, in a prospective, longitudinal study on 74 children and adolescents Jones et al. found that the volume of the joint cartilage increased in most children during an average observation period of 1.6 years, in particular in boys, in younger subjects and in physically active children [19]. General physical activity was assessed by the authors retrospectively. Since our data were collected in a cross-sectional study design, these results are not in conflict but raise questions that need to be addressed in a successor study. Remaining gaps may be clarified by a longitudinal study of articular cartilage morphology in children over a longer period, but for certain predefined sport types including control groups. The higher rate of cartilage growth in boys versus girls reported in Jones et al. is also interesting with respect to thicker cartilage in boys within our study.

In absence of pathologies, deformities or clinical symptoms of the lower extremity or knee, a wide range of cartilage thicknesses at a fixed position (0.4–5.0 mm) could be found, which is in accordance with previous studies on healthy adults [10, 36]. Beside effects that origin from differences between frequently varying mechanical loading and static mechanical loading, different pressure distributions should be considered as a possible influencing factor on cartilage thickness. Thinning of cartilage at one location within the knee joint may be associated with greater thickness elsewhere, as already demonstrated for thin trochlear cartilage on the femur correlating with thicker patellar cartilage on the lateral side of the vertical ridge resulting in thinning on the medial side [36]. This appear to directly support our assumption that observed diametrically different changes in cartilage thickness at the medial femoral condyle after mechanical loading can be attributed to individual deviations in the joint geometry. The resulting different load distributions could have compressed the cartilage to diverse extents locally. In addition, different biomechanical properties of the cartilage could lead to unequal adaptation and compressibility. In the long term, these properties might also be influenced by typical movement patterns of sports practiced intensively. Measurable differences immediately after defined mechanical load could also indicate that ultrasound-guided cartilage thickness determination could be used to directly assess the effect of a therapeutic intervention, such as correction of extremity deformities. However, no significant correlation could be found between the load-induced change in thickness and the types of sport investigated.

Finally, the potential of MSUS for longitudinal and repetitive monitoring of cartilage thickness on an individual basis should be emphasised here. If thinning is observed, early corrective strategies could be implemented to preserve joint health. In a recently published study of 118 women >50 years of age, ultrasonography demonstrated a decrease in cartilage thickness at the medial femoral condyle accompanied by an increase in echo intensity during progressive knee OA. However, early OA stages by Kellgren–Lawrence grading scale were not yet significantly different from the control group [28].

For noninvasive evaluation of cartilage status, MRI (especially when using T2 mapping) is currently the most commonly used technique for providing information on the dimension of articular cartilage and the quality of the cartilage matrix [14, 26, 48]. Nevertheless, its cost, the limited availability, the long examination time and demanding personnel requirements restrict the widespread use of MRI in early diagnosis [14]. Ultrasound examination, in contrast, could be a widely applicable, fast and cost-effective alternative to determine knee health-related factors noninvasively and pain-free, usable also for serial measurements as part of long-term preventive monitoring. Establishing normative data in structural ultrasound is important in clinical practice and for comparison of data [39, 40, 50–52]. In children and adolescents with rheumatic disease, MSUS is applied successful in diagnosis and disease monitoring. It is especially promising in the assessment of JIA, as a reliable method to precisely document and monitor the synovial inflammation process [2, 24, 25, 44].

The major strength of this study is the large number of participants, still comprising large subgroups when divided by age, sex and practiced types of sport. The possibility to obtain data within a physiological range of healthy, physically active children and adolescents by excluding orthopaedic pathologies is a significant advantage of the study. Examination and measurement by a single investigator provided well comparable results excluding interpersonal variability.

Due to this though, interinvestigator-related bias and its potential impact could not be assessed and evaluated within this single-performer study design. Moreover, test–retest studies cannot address investigator-related reliability issues [21]. However, interpersonal reproducibility was tested by Spannow et al. by ultrasound-guided cartilage thickness assessment of a skilled and nonskilled investigator on a collective of 11 healthy children in different joints [42]. Given a level of agreement between the two examiners within 95% confidence interval, the authors suggested that the variability was mainly related to the positioning of the joints and the sonographic transducer within the measurements. A major limitation of this study is the lack of a comparison with an imaging method such as MRI or computed tomography as well as comparison with a less active, for example, sedentary, control group. Moderate mechanical loading and/or short-term mechanical loading might have a bias on current data. Serial measurements within certain time intervals, for example, after weeks or months, are also missing. Assessments were limited due to hygienic restrictions and lockdown periods within the COVID-19 pandemic.

Taken together, ultrasound-guided measurement of the cartilage thickness at the medial femoral condyle was shown to display a high intra-individual reliability. Inter-individual inaccuracies were then considered negligible in healthy knees. Further benefits of MSUS, such as noninvasiveness or the easy assessable, fast and comparatively inexpensive application in clinical practice and research, are essential, especially in paediatric patients, to enable frequent use. Physiological values of cartilage thickness can thus be documented on a broad data base, along with conspicuous discrepancies, which may help to reveal processes from the healthy, juvenile knee to the degeneratively altered knee of the adult. Factors influencing these processes can be explored on a low-threshold, child-friendly basis, such as sports that damage or protect cartilage. Additionally, progress and effectiveness of therapeutic interventions for musculoskeletal disorders affecting the knee may be supported by ultrasound examinations in individual cases.

CONCLUSION

The method of ultrasound-guided cartilage thickness measurement at the medial femoral condyle showed good reproducibility and was capable of depicting the influence of age, sex and type of sport in athletically active children and adolescents. Together with its feasibility in paediatrics and ease of implementation, the method is a suitable tool for research and clinical use to evaluate possible risk factors for later cartilage damage in the knee.

AUTHOR CONTRIBUTIONS

Dirk Schneider was involved in conception and design, was responsible for acquisition of data, data analysis and interpretation of data, was involved in first draft, critically revised the manuscript and gave final approval. Regine Weber was involved in conception and design, supervised the study implementation, was involved in the interpretation of data, critically revised the manuscript and gave final approval. Nasenien Nourkami-Tutdibi was involved in the interpretation of data, critically revised the manuscript and gave final approval. Michelle Bous, Sybelle Goedicke-Fritz and Muriel Charlotte Hans critically revised the manuscript and gave final approval. Steve Hein was involved in conception and design, critically revised the manuscript and gave final approval. Milan Anton Wolf and Stephan Landgraeber were involved in conception and design, critically revised the manuscript and gave final approval. Michael Zemlin was involved in conception and design, supervised the study implementation, critically revised the manuscript and gave final approval. Elisabeth Kaiser was involved in conception and design, supervised the study implementation, was responsible for data analysis and interpretation, and wrote and submitted the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author (Elisabeth Kaiser) upon reasonable request.

ETHICS STATEMENT

This study was approved by the Ethics Committee of Saarland (permission number: 191/19). Participants and their legal guardians were informed about the background and necessity of the study, the procedure and the rights of participants. Informed written consent of the legal guardians was obtained prior to any intervention.

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