Published in final edited form as:

AJR Am J Roentgenol. 2018 December ; 211(6): 1369–1375. doi:10.2214/AJR.18.20026.

Maturation-Related Changes in T2 Relaxation Times of Cartilage and Meniscus of the Pediatric Knee Joint at 3 T

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Abstract

OBJECTIVE.—The objective of our study was to use a T2 mapping sequence performed at 3 T to investigate changes in the composition and microstructure of the cartilage and menisci of the pediatric knee joint during maturation.

MATERIALS AND METHODS.—This retrospective study was performed of MRI examinations of 76 pediatric knees without internal derangement in 72 subjects (29 boys [mean age, 12.5 years] and 43 girls [mean age, 13.0 years]) who were evaluated with a sagittal T2 mapping sequence. T2 relaxation time values were quantitatively measured in eight cartilage subregions and in the medial and lateral menisci. Wilcoxon rank sum and Kruskal-Wallis tests were used to analyze the relationship between cartilage and meniscus T2 relaxation time values and sex and skeletal maturation, respectively. A multivariate linear regression model was used to investigate the independent association between cartilage T2 relaxation time values and age, weight, and body mass index (BMI [weight in kilograms divided by the square of height in meters]).

RESULTS.—There were no significant sex differences ($p = 0.26$ – 0.91) in T2 relaxation time values for cartilage or meniscus. T2 relaxation time values in each individual cartilage subregion significantly decreased ($p < 0.001$) with progressive maturation. T2 relaxation time values in the lateral meniscus significantly increased ($p = 0.001$) with maturation, whereas T2 relaxation time values in the medial meniscus did not significantly change ($p = 0.82$). There was a significant association ($p < 0.001$) between cartilage T2 relaxation time values and age independent of weight and BMI, but no significant association between cartilage T2 relaxation time values and weight ($p = 0.06$) and BMI ($p = 0.20$) independent of age.

CONCLUSION.—Cartilage T2 relaxation time values significantly decreased in all cartilage subregions and meniscus T2 relaxation time values significantly increased in the lateral meniscus

during maturation. These changes in T2 relaxation time values reflect age-related changes in tissue composition and microstructure.

Keywords

children; knee; normal T2 values; skeletal maturation; T2 mapping; T2 relaxation time

T2 mapping sequences have emerged as highly sensitive quantitative MRI techniques that can be used to detect compositional and microstructural changes in the cartilage extracellular matrix [1–3]. The T2 relaxation time of cartilage is influenced by multiple factors including hydration, macromolecular content, and organization of the collagen fiber network [4–8]. In adults, cartilage T2 relaxation time values have been shown to increase with age, reflecting either senescent changes [9] or early premorphologic cartilage degeneration or a combination of both [10–13]. Previous studies have also found that focal increases in cartilage T2 relaxation time values in areas of morphologically normal cartilage in adult patients with knee pain correspond to surgically confirmed early cartilage degeneration [14]. In children, cartilage T2 relaxation time values have been shown to increase in patients with juvenile idiopathic arthritis and patellofemoral instability, likely owing to disease-related changes in cartilage composition and microstructure [10, 15].

The more widespread use of T2 mapping sequences in children has been partially hindered by a paucity of studies in the literature describing the normal changes in cartilage that occur during maturation. Prior studies on skeletally immature children have shown an age- and maturation-dependent decrease in cartilage T2 relaxation time values [16–19]. However, these results have been derived predominately from studies performed on the patellar cartilage using 1.5-T MRI scanners. Therefore, it is uncertain whether this trend is generalizable to the remainder of the cartilage of the pediatric knee joint and to higher-field-strength 3-T MRI scanners. Furthermore, no prior study to date has documented normal changes in the meniscus that occur during maturation. Therefore, the purpose of our study was to use a T2 mapping sequence at 3 T to investigate changes in the composition and microstructure of the cartilage and menisci of the pediatric knee joint during maturation.

Materials and Methods

Study Group

Our study was performed in compliance with HIPAA regulations, with the approval from the institutional review board of the American Family Children's Hospital and a waiver of informed consent.

Subjects were selected from a database of all pediatric patients, defined as 18 years old or younger, who underwent routine 3-T MRI of the knee at the American Family Children's Hospital between August 1, 2011, and March 31, 2017. Exclusion criteria were a history of or MRI findings of internal knee derangement, congenital skeletal dysplasia, acquired skeletal deformity, prior instrumentation or implanted hardware, infectious or inflammatory arthropathy, malignancy, or recent high-impact trauma. The medical records of all subjects were reviewed, and the age and sex at the time of the MRI examination were recorded for all

subjects, and the weight and body mass index (BMI [weight in kilograms divided by the square of height in meters]) measured within 6 months of the MRI examination were recorded for subjects for whom this information was available.

Skeletal maturation was determined using the appearance of the distal femur physis on both coronal and sagittal fluid-sensitive sequences. An open physis, reflecting skeletal immaturity, was defined as a uniform, well-defined band of hyperintense signal of the growth plate cartilage. A closing physis, reflecting upcoming skeletal maturity, was defined as narrowing, indistinctness, or complete loss of the hyperintense signal of the cartilage that involved at least 25% of the growth plate. A closed physis, reflecting skeletal maturity, was defined as complete loss of the hyperintense signal of the growth plate cartilage.

MRI Examination

All subjects underwent an MRI examination of the knee on the same 3-T scanner (Sigma Excite HDx, GE Healthcare) at the American Family Children's Hospital using an 8-channel phased-array extremity coil (Precision Eight TX/TR High Resolution Knee Array, Invivo). The MRI examination consisted of multiplanar proton density-weighted and T2-weighted fast spin-echo sequences with and without fat suppression and a commercially available T2 mapping sequence (Cartigram, GE Healthcare). The imaging parameters of all sequences are summarized in Table 1.

Quantitative Analysis of T2 Maps

Sagittal T2 map images of each knee in the study group were created using a custom-made linear least-squares fitting method developed in Matlab 2016 (MathWorks) [20]. A radiology resident with 3 years of clinical experience segmented the cartilage and meniscus of the entire knee joint on the T2 map images using custom-made semiautomated software developed in Matlab under the supervision of a fellowship-trained pediatric radiologist with 5 years of clinical experience and 3 years of research experience performing quantitative cartilage analysis.

For cartilage analysis, the articular-side epiphyseal cartilage of the entire knee joint was semiautomatically outlined on each slice, which included both the articular and articular-sided epiphyseal cartilage in subjects with open and closing physes and included only the articular cartilage in subjects with closed physes [19]. The cartilage boundaries were segmented at the bone-cartilage interface and the cartilage articular surface on the gray-scale T2 map images, which provided good tissue contrast for distinguishing joint structures. The final contours were verified on the T2 mapping source images to ensure accuracy. T2 map slices were included only if the cartilage was clearly depicted without motion or partial volume artifacts and its margins were clearly defined. The cartilage was divided into the following eight subregions: the patella, trochlea, central medial femoral condyle, posterior medial femoral condyle, medial tibial plateau, central lateral femoral condyle, posterior lateral femoral condyle, and lateral tibial plateau [21, 22]. The anterior and posterior margins of the meniscus demarcated the junctions between the trochlea and the central femoral condyle and between the central and posterior femoral condyles, respectively (Fig. 1). The mean T2 relaxation time values of all pixels within the ROIs placed around each cartilage

subregion and the mean T2 relaxation time values of all cartilage subregions combined were calculated. Individual pixels with T2 relaxation time values greater than 100 milliseconds were considered to represent partial volume averaging with joint fluid and were excluded from the analysis. Similarly, pixels with T2 relaxation time values less than 5 milliseconds were considered to represent ossified bone and were also excluded from analysis.

For meniscus analysis, the anterior horn, body, and posterior horn of the medial and lateral menisci were semiautomatically outlined on each slice. The meniscus boundaries were segmented on the grayscale T2 map images, and the final contours were verified on the T2 mapping source images to ensure accuracy. T2 map slices were included only if the meniscus was clearly depicted without motion or partial volume artifacts and its margins were clearly defined. To avoid partial volume effects, the upper-and lowermost borders of the meniscus and the peripheralmost slices were excluded. The mean T2 relaxation time values of all pixels within the ROIs placed around the entire medial and lateral menisci were calculated. Individual pixels with T2 relaxation time values greater than 100 milliseconds were considered to represent partial volume averaging with joint fluid and were excluded from the analysis.

Statistical Analysis

Statistical analysis was performed using the R program environment (version 3.3.1, R Foundation for Statistical Computing). All statistical tests were two-sided with significance defined as a p value of < 0.05 .

Wilcoxon rank sum tests were used to compare age and the cartilage and meniscus T2 relaxation time values between male and female subjects. Kruskal-Wallis tests were used to compare age and the cartilage and meniscus T2 relaxation time values of subjects with different degrees of skeletal maturation. The Wilcoxon signed rank test was used to compare the cartilage T2 relaxation time values in the different cartilage subregions. Spearman rank correlation coefficients with 95% CIs were used to investigate the univariable association between cartilage and meniscus T2 relaxation time values with age, weight, and BMI. The closer the correlation coefficient, r , was to 1 or -1 , the stronger the positive or negative correlation. A multivariate linear regression model was used to investigate the independent association between cartilage T2 relaxation time values with age and weight and cartilage T2 relaxation time values with age and BMI. The analyses involving weight and BMI were conducted within the subset of subjects who had weight and BMI measurements recorded in the medical records within 6 months of the MRI examination.

Results

The study group consisted of 72 subjects (76 knees) between 3 and 18 years old (29 boys with a mean age of 12.5 years and 43 girls with a mean age of 13.0 years) who underwent a total of 76 knee MRI examinations. Sixty-six subjects had weight and BMI measurements recorded in the medical records within 6 months of the MRI examination. Subject demographics are listed in Table 2.

Variations in Cartilage and Meniscus T2 Relaxation Time Values by Cartilage Subregion

Cartilage T2 relaxation time values varied in the different cartilage subregions. The lowest T2 relaxation time value was in the lateral tibial plateau, and the highest T2 relaxation time value was in the trochlea, and these values were significantly different ($p < 0.001$). For both tibiofemoral compartments, T2 relaxation time values were significantly lower ($p < 0.001$) in the tibial plateau than the central femoral condyle. There was no significant difference between the T2 relaxation time values in the central femoral condyles and the posterior femoral condyles ($p = 0.32$ for the medial femoral condyle and $p = 0.06$ for the lateral femoral condyle). The T2 relaxation time value of the lateral meniscus was significantly higher ($p < 0.001$) than the medial meniscus (Table 3).

Variations in Cartilage and Meniscus T2 Relaxation Time Values by Sex

There were no significant differences in T2 relaxation time values for cartilage ($p = 0.53$ for all cartilage subregions combined and $p = 0.26$ – 0.91 for each cartilage subregion) or for menisci ($p = 0.76$ for medial meniscus and $p = 0.33$ for lateral meniscus) between male and female subjects (Table 3).

Variations in Cartilage and Meniscus T2 Relaxation Time Values by Age and Skeletal Maturation

Forty-one knees had open physes, 15 knees had closing physes, and 20 knees had closed physes. There was a significant difference ($p < 0.001$) in the age of knees with open, closing, and closed physes. T2 relaxation time values in all cartilage subregions combined and in each individual cartilage subregion significantly decreased ($p < 0.001$) with progressive maturation (Table 3 and Fig. 2). There was a moderate negative correlation between cartilage T2 relaxation time values and age ($r = -0.65$ for all cartilage subregions combined and $r = -0.56$ to -0.69 for each cartilage subregion) (Table 4). The relationship between cartilage T2 relaxation time values and age remained significant ($p < 0.001$) in the multivariate model. For every year increase in age, the cartilage T2 relaxation time value decreased by 0.86 millisecond (mean) while holding the weight constant and decreased by 1.05 milliseconds (mean) while holding the BMI constant.

T2 relaxation time values in the lateral meniscus significantly increased ($p = 0.001$) with maturation, whereas the T2 relaxation time values in the medial meniscus did not significantly change ($p = 0.82$) (Table 3). There was a weak positive correlation between the lateral meniscus T2 relaxation time values and age ($r = 0.40$). There was no correlation between medial meniscus T2 relaxation time values and age ($r = -0.04$) (Table 4).

Variations in Cartilage and Meniscus T2 Relaxation Time Values by Weight and Body Mass Index

There was a moderate to strong negative correlation between cartilage T2 relaxation time values and weight ($r = -0.67$ for all cartilage subregions combined and $r = -0.59$ to -0.71 for each cartilage subregion). There was a moderate negative correlation between cartilage T2 relaxation time values and BMI ($r = -0.53$ for all cartilage subregions combined and $r = -0.44$ to -0.60 for each cartilage subregion) (Table 4). The relationship between cartilage T2 relaxation time and weight ($p = 0.06$) and cartilage T2 relaxation time and BMI ($p = 0.20$)

did not remain significant in the multivariate model, which indicated no significant association independent of age.

There was a weak positive correlation between lateral meniscus T2 relaxation time values and weight ($r = 0.36$) and BMI ($r = 0.42$). There was no correlation between medial meniscus T2 relaxation time values and weight ($r = 0.08$) or BMI ($r = 0.17$) (Table 4).

Discussion

Our study investigated region-, sex-, age-, skeletal maturation-, weight-, and BMI-dependent differences in cartilage and meniscus T2 relaxation time values of the pediatric knee joint at 3 T. The results of our study serve as a first step toward establishing a range of normal cartilage and meniscus T2 relaxation time values for the pediatric knee joint similar to recently published T2 relaxation time reference standards for cartilage [9] and meniscus [23, 24] for the adult knee joint. Our study identified significant differences in T2 relaxation time values between the different cartilage subregions and between the medial meniscus and lateral meniscus of the pediatric knee joint. Our study also documented age- and maturation-dependent differences in T2 relaxation time values in all cartilage subregions and in the lateral meniscus.

The results of our study showed that T2 relaxation time values in all cartilage subregions significantly decreased with progressive skeletal maturation. Prior studies performed using 1.5-T scanners of skeletally immature children have also shown significant ($p < 0.05$) age- and maturation-dependent decreases in cartilage T2 relaxation time values in the patella [16–19]. Our study confirms that identical decreases in cartilage T2 relaxation time values with increasing age and skeletal maturity occur on all articular surfaces of the pediatric knee joint and are not influenced by the magnetic field strength of the MRI scanner. The decrease in cartilage T2 relaxation time values with increasing age and maturation reflects a combination of normal physiologic increase in collagen content and organization [16] and the loss of the acrophysis (growth plate cartilage of the secondary ossification center) and unossified epiphyseal hyaline cartilage [17–19, 25]. Structurally, juvenile cartilage, which develops with age in response to mechanical loading, has a less organized zonal pattern of collagen fibrils [26]. Juvenile cartilage also contains a relatively higher concentration of collagen and proteoglycans and undergoes a higher rate of internal remodeling [16, 27, 28].

Our study identified significant region-dependent differences in cartilage T2 relaxation time values of the pediatric knee joint. The cartilage T2 relaxation time values on the tibial plateau were consistently lower than the cartilage T2 relaxation time values on the corresponding femoral condyle for the medial and lateral compartments. This pattern that has been recognized in adults [9] but has not been previously reported in children to our knowledge. However, there was no significant difference in cartilage T2 relaxation time values between the posterior femoral condyle and the central femoral condyle in both the medial and lateral compartments. A previous study in the adult knee joint has shown significantly higher ($p < 0.001$) cartilage T2 relaxation time values in the posterior femoral condyles than the central femoral condyles in both the medial and lateral compartments [21]. This difference was mainly attributed to the magic angle effect, which occurs when cartilage

is aligned 55° relative to the main magnetic field [29]. The magic angle effect on the cartilage of the posterior femoral condyles is likely to be less prominent in the pediatric knee joint than the adult knee joint because of the decreased organization of the collagen fiber network of juvenile cartilage [26].

Our study found no significant sex-dependent differences in cartilage T2 relaxation time values of the pediatric knee joint. This finding is consistent with a previously published study on cartilage T2 relaxation time reference standards of the adult knee joint, in which a significant sex-dependent difference ($p < 0.05$) was observed only for the cartilage of the medial femoral condyle [9]. However, our results differ from a previously published study involving children and young adults, which found that male subjects had significantly higher ($p < 0.05$) cartilage T2 relaxation time values than female subjects [18]. This difference in values was attributed mainly to sex-related differences in the timing of skeletal maturation. However, the previous study evaluated only the patellar cartilage and investigated subjects with a wider age range, with individuals as young as 5 years old included in the skeletally immature group and individuals as old as 22 years included in the skeletally mature group.

Juvenile cartilage, which develops with age in response to mechanical loading, has a less organized zonal pattern of collagen fibrils than adult cartilage [26]. Differences in mechanical loading of the pediatric knee joint due to weight and BMI may have an influence on the rate of skeletal maturation and thus the measured cartilage T2 relaxation time values. Our study found a moderate to strong negative correlation between cartilage T2 relaxation time values and weight and a moderate negative correlation between cartilage T2 relaxation time values and BMI. However, multivariate analysis showed no significant association between cartilage T2 relaxation time values and weight or BMI independent of age. Thus, the negative correlation is likely due to the fact that weight and BMI were higher in skeletally mature subjects who had intrinsically lower cartilage T2 relaxation time values. Our results do not support the assumption that greater mechanical loading due to higher weight or BMI influences cartilage T2 relaxation time values of the pediatric knee joint, either by accelerating the rate of tissue remodeling or causing early premorphologic cartilage degeneration.

Our study showed no significant difference in meniscus T2 relaxation time values of the pediatric knee joint between male and female subjects. However, there were significantly higher T2 relaxation time values in the lateral meniscus than the medial meniscus. Our results are in direct contrast with previous studies performed in adults, which showed significantly higher ($p < 0.05$) meniscus T2 relaxation time values in women than men [24] but no significant difference in meniscus T2 relaxation time values between the medial meniscus and lateral meniscus [23]. This discordance may be the result of differences in the ROIs analyzed. The T2 relaxation time values of the entire menisci were measured in our study, whereas the T2 relaxation time values of only the posterior horns were measured in the studies of adults. The meniscus T2 relaxation time values obtained in our study in children were much higher than those obtained in other studies in adults [23, 24]. However, the absolute values are difficult to compare because of the different imaging parameters used to measure T2 relaxation time.

Our study found that meniscus T2 relaxation time values increased with maturation, which may reflect changes in meniscus composition and microstructure during growth. Meniscus maturation in a swine model showed a decrease in type I collagen content and an increase in type II collagen and glycosaminoglycan content, reflecting a specific differentiation of meniscus cells with maturation toward a more cartilaginous phenotype. The more cartilaginous phenotype of the mature meniscus may be associated with a higher T2 relaxation time than the pure fibrocartilaginous phenotype of the immature meniscus [30]. However, it is unknown why this maturation-dependent increase in meniscus T2 relaxation time values was observed for only the lateral meniscus. One possible explanation is differences in the vascularity changes of the medial and lateral menisci that occur with maturation. The vascularity of the medial and lateral menisci in children has been shown to significantly decrease with maturation [31], which results in a decrease in meniscus T2 relaxation time values [32]. Because the lateral meniscus has lower vascularity than the medial meniscus due to an avascular zone in the region of the popliteal hiatus [33], the vascularity-related decrease in T2 relaxation time values with maturation is likely more pronounced in the medial meniscus than the lateral meniscus. The greater vascularity-related decrease in the relaxation time values in the medial meniscus with maturation may offset the increase in T2 relaxation time values due to differentiation of meniscus cells toward a more cartilaginous phenotype.

Our study has several limitations. One limitation is the retrospective nature of our study, which used preexisting MRI and clinical data. In particular, the weight and BMI of subjects were obtained from the medical records and were measured within 6 months of the MRI examinations. Although weight and BMI are unlikely to change substantially within a 6-month time period, this possibility cannot be completely excluded. The retrospective nature of our study also did not allow us to control for the effect of joint loading on cartilage T2 relaxation time values [34]. However, it is worth noting that the 25-minute routine clinical knee MRI protocol was always performed before the T2 mapping sequence, which allowed all subjects to have at least some degree of joint unloading before the measurement of cartilage and meniscus T2 relaxation times. Furthermore, our study did not investigate depth-dependent changes of cartilage T2 relaxation time values at different stages of maturation. However, this depth-dependent analysis has been performed in previous studies for juvenile patellar cartilage [17–19]. In addition, the T2 mapping sequence used in our study was optimized to evaluate cartilage and not meniscus and used much longer TEs than the sequences used in previous studies in adults to measure meniscus T2 relaxation times [23, 24]. Our choice of imaging parameters may have created bias in the absolute values of our meniscus T2 relaxation time measurements. However, it would not have influenced the investigation of region-, sex-, age-, maturation-, weight-, and BMI-dependent differences in meniscus T2 relaxation time values. Finally, although all subjects had normal MRI examinations of the knee with no findings of joint abnormalities and no additional diagnoses at the time of medical record review, they cannot be considered healthy, asymptomatic volunteers because all individuals had knee symptoms that warranted the MRI evaluation.

In conclusion, our study found that T2 relaxation time values significantly decreased with increasing age and skeletal maturity in cartilage on all articular surfaces and significantly increased in the lateral meniscus of the pediatric knee joint. Our findings also showed that

cartilage and meniscus T2 relaxation time values were not significantly influenced by sex, weight, or BMI. The information gained in our study serves as a first step toward establishing a range of normal cartilage and meniscus T2 relaxation time values for the pediatric knee joint. However, additional prospective studies on larger numbers of healthy, asymptomatic children using a wide variety of MRI scanners and T2 mapping sequences are needed to establish T2 relaxation time reference standards for knee cartilage and meniscus. These reference standards in children would be helpful for distinguishing between normal T2 relaxation time changes due to maturation and T2 relaxation time changes due to tissue degeneration.

Acknowledgments

Supported by the National Institute of Arthritis and Musculoskeletal and Skin Diseases (grant R01-AR068373-01). R. Kijowski receives research support from GE Healthcare and is a consultant for Boston Imaging Core Laboratory.

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Fig. 1—. Sagittal gray-scale T2 map image through medial compartment of knee joint in skeletally immature 13-year-old boy illustrates method used for cartilage segmentation. Segmentation software semiautomatically outlined cartilage on each image slice, and dashed lines are used to divide cartilage into subregions. Subregions included patella and tibial plateau (light blue), trochlea (green), central femoral condyle (dark blue), and posterior femoral condyle (red). Green square allows manual movement of dashed lines; arrow and R denote right knee.

Fig. 2—

Changes in T2 relaxation time values of cartilage and meniscus with age and skeletal maturation. Scale shows T2 relaxation times in milliseconds.

A–C, Sagittal color-scale T2 map images through lateral compartment of knee joint in skeletally immature 5-year-old girl with open physes (**A**), skeletally immature 8-year-old girl with open physes (**B**), and skeletally mature 16-year-old boy with closed physes (**C**) show progressive replacement of unossified epiphyseal cartilage with bone on lateral femoral condyle (*arrowheads*) and lateral tibial plateau. Note predominantly green and yellow color map signal intensity of cartilage in younger child corresponding to higher T2 relaxation times and predominantly yellow, red, and black color map signal intensity of cartilage of older children corresponding to lower T2 relaxation time. Black color map signal intensity indicates pixels with T2 relaxation time below minimum color threshold of 25 milliseconds. Predominantly black color map signal intensity of posterior horn of lateral meniscus (*arrows*) corresponds to lower T2 relaxation time.

TABLE 1:

Imaging Parameters of the Sequences Performed in Knee MRI Examinations

Parameters	Axial FS T2-Weighted FSE	Coronal PDW FSE	Coronal FS PDW FSE	Sagittal PDW FSE	Sagittal FS T2-Weighted FSE	Sagittal T2 Mapping
TR (ms)	4300	1800	2000	2000	5300	1500
TE (ms)	77	20	20	20	80	9, 18, 27, 36, 44, 53, 62, 71
Flip angle (°)	90	90	90	90	90	90
Matrix size	448 × 224	384 × 224	384 × 224	384 × 224	384 × 224	320 × 192
FOV (cm)	18	14	14	14	14	16
Section thickness (mm)	3	2	2	2	3	3
Bandwidth (kHz)	41.7	31.2	31.2	31.2	41.7	31.3
Echo-train length	21	4	4	4	20	NA
No. of signals acquired	4	2	2	2	3	1
Imaging time (min:s)	3:30	3:25	3:26	3:26	3:16	5:00–6:00

Note—FS = fat-suppressed, FSE = fast spin-echo, PDW = proton density-weighted, NA = not applicable.

TABLE 2:

Characteristics of 76 Knees (72 Patients) in Study Group

Characteristic	Value	Age (Mean $\pm$ SD)	<i>p</i>
Sex, no. of knees			0.85
Male	32	12.8 $\pm$ 4.1	
Female	44	13.0 $\pm$ 3.2	
Skeletal maturation, no. of knees			< 0.001
Immature	41	10.5 $\pm$ 3.1	
Maturing	15	14.7 $\pm$ 1.0	
Mature	20	16.5 $\pm$ 0.9	
BMI ^a , no. of subjects			
Underweight (< 18.5)	17		
Normal weight (18.5–24.9)	37		
Overweight (25.0–29.9)	8		
Obese ($\geq$ 30.0)	4		

^aBMI (body mass index) is weight in kilograms divided by the square of height in meters. Data were available for 66 subjects.

TABLE 3:
T2 Relaxation Time Values of Cartilage and Meniscus Based on Sex and Skeletal Maturation

Characteristic	Sex			Physical Patency		
	All (n = 76 Knees)	Male (n = 32 Knees)	Female (n = 44 Knees)	Open (n = 41 Knees)	Closing (n = 15 Knees)	Closed (n = 20 Knees)
Age (y), mean (SD)	12.9 (3.6)	12.8 (4.1)	13.0 (3.2)	10.5 (3.1)	14.7 (1.0)	16.5 (0.9)
T2 relaxation time (ms), mean (SD)						
Cartilage						
Trochlea	44.7 (5.6)	45.3 (6.2)	44.3 (5.2)	47.8 (5.6)	41.4 (2.5)	40.7 (2.8)
Patella	47.2 (4.8)	47.5 (5.3)	47.1 (4.4)	49.7 (5.0)	44.7 (2.4)	44.2 (2.4)
Medial tibial plateau	43.5 (6.9)	43.8 (7.1)	43.3 (6.8)	46.9 (7.1)	38.8 (3.6)	40.2 (4.2)
Central MFC	42.2 (6.5)	42.7 (7.3)	41.8 (6.0)	45.5 (6.5)	39.0 (3.3)	37.8 (4.7)
Posterior MFC	45.3 (6.2)	45.8 (7.2)	44.9 (5.5)	48.9 (6.0)	42.5 (3.0)	40.0 (2.7)
Lateral tibial plateau	45.9 (7.9)	47.3 (8.6)	44.9 (7.3)	50.3 (8.1)	42.1 (3.0)	39.8 (3.2)
Central LFC	39.6 (6.2)	40.7 (6.7)	38.8 (5.7)	42.7 (6.1)	36.5 (3.0)	35.7 (4.6)
Posterior LFC	45.1 (5.9)	45.2 (6.9)	45.0 (5.1)	48.2 (5.9)	42.1 (3.4)	40.9 (3.0)
Meniscus	45.9 (6.3)	46.7 (7.3)	45.4 (5.6)	49.2 (6.7)	42.7 (3.0)	41.8 (2.8)
Medial	28.7 (3.5)	28.6 (3.7)	29.0 (3.2)	29.0 (3.4)	28.1 (2.6)	28.7 (4.2)
Lateral	31.3 (4.2)	31.8 (4.8)	30.7 (3.2)	30.0 (4.3)	32.4 (2.9)	33.2 (3.9)

Note—MFC = medial femoral condyle, LFC = lateral femoral condyle.

TABLE 4:

Spearman Rank Correlation Coefficients Describing the Association Between Cartilage and Meniscus T2 Relaxation Time Values and Age, Weight, and Body Mass Index

Structure	Spearman Rank Correlation Coefficient		
	Age (y)	Weight (kg)	Body Mass Index ^a
Cartilage	-0.65 (-0.76 to -0.49)	-0.67 (-0.78 to -0.51)	-0.53 (-0.68 to -0.32)
Trochlea	-0.59 (-0.72 to -0.42)	-0.63 (-0.76 to -0.46)	-0.52 (-0.68 to -0.32)
Patella	-0.56 (-0.70 to -0.39)	-0.59 (-0.73 to -0.41)	-0.44 (-0.62 to -0.23)
Medial tibial plateau	-0.59 (-0.72 to -0.43)	-0.62 (-0.75 to -0.45)	-0.49 (-0.65 to -0.28)
Central MFC	-0.66 (-0.77 to -0.51)	-0.70 (-0.81 to -0.56)	-0.60 (-0.74 to -0.42)
Posterior MFC	-0.69 (-0.79 to -0.54)	-0.64 (-0.76 to -0.47)	-0.48 (-0.64 to -0.26)
Lateral tibial plateau	-0.61 (-0.73 to -0.44)	-0.62 (-0.75 to -0.45)	-0.48 (-0.65 to -0.27)
Central LFC	-0.64 (-0.75 to -0.48)	-0.71 (-0.81 to -0.57)	-0.60 (-0.73 to -0.42)
Posterior LFC	-0.59 (-0.72 to -0.42)	-0.60 (-0.74 to -0.42)	-0.47 (-0.64 to -0.25)
Meniscus			
Medial	-0.04 (-0.26 to 0.19)	0.08 (-0.17 to 0.31)	0.17 (-0.08 to 0.39)
Lateral	0.40 (0.19-0.57)	0.36 (0.13-0.55)	0.42 (0.19-0.60)

Note—Values in parentheses are 95% CIs. MFC = medial femoral condyle, LFC = lateral femoral condyle.

^aWeight in kilograms divided by the square of height in meters.