Compartment Differences in Knee Cartilage Volume in Healthy Adults

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ABSTRACT. ***Objective.*** It is unclear why there are compartmental differences in the risk of knee osteoarthritis (OA). We investigated whether there are compartment differences in the volume of knee cartilage in healthy persons and identified determinants of medial and lateral tibial cartilage volume.

Methods. A total of 166 healthy persons (age range 21–79 yrs, 58% female) with clinically and structurally normal knees were examined. Thickness and volume were determined for the medial and lateral tibial articular cartilages by processing images acquired in the sagittal plane using T1 weighted fat saturated magnetic resonance imaging on an independent work station.

Results. In every subject, the lateral tibial cartilage was thicker than medial cartilage (mean 6.43 ± SD 1.25 mm vs 4.49 ± 0.81 mm; $p < 0.001$), and the volume of cartilage was greater (2.34 ± 0.70 ml vs 1.82 ± 0.56 ml; $p < 0.001$). This effect persisted when values for men and women were analyzed separately. Both medial and lateral tibial cartilage volume and thickness were greater in men compared to women, independent of body mass index and bone size. The reduction in medial and lateral tibial cartilage volume and thickness was inversely related to the current level of physical activity.

Conclusion. This study supports the knee compartment differences in cartilage volume recently reported in children. It is likely these differences are maintained throughout life. The possibility that the amount of knee cartilage in an individual is a risk factor for OA now needs to be tested in longitudinal studies. (J Rheumatol 2002;29:554–6)

Key Indexing Terms:
OSTEOARTHRITIS TIBIOFEMORAL COMPARTMENT KNEE CARTILAGE VOLUME

Osteoarthritis (OA) is the major cause of disability in those over age 65 years[1]. Sex and compartmental differences in knee OA are well described[2,3]. Women have between 1.5 and 4-fold greater risk than men[2], while medial compartment disease is 4 times more common than lateral compartment disease[3]. The reasons for these variations are unclear. One potential explanation is that the preexisting amount of cartilage may be important. In support of this, we recently showed that men have more knee cartilage than women, independent of differences in body mass index (BMI) and bone size, in both adults[4] and children[5]. In children, we also reported that in the lateral knee compartment, articular cartilage was thicker and of larger volume than in the medial compartment[5]. The aim of this study was to determine whether there are compartmental differences in knee cartilage volume and thickness in healthy adults and to identify determinants of lateral and medial tibial cartilage.

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MATERIALS AND METHODS

We examined 166 asymptomatic, healthy subjects with a structurally normal knee on MRI (including no features of OA) and no knee pain, stiffness, or functional abnormalities as measured by the Western Ontario and McMaster Universities OA Index (WOMAC)[6]. Mass was measured to the nearest 0.1 kg (shoes and bulky clothing removed) using a single pair of electronic scales. Height was measured to the nearest 0.1 cm (shoes removed) using a stadiometer. BMI (weight/height^2, kg/m^2) was calculated. Current total activity was a composite score of total amount of walking (0–4) + activity at home (0–4) + sporting activity (0–4)[7]. Each subject had an MRI performed on their dominant knee, defined as the lower limb from which they step off when walking.

Knee cartilage volume was determined by means of image processing on an independent workstation as described[4,5]. Coefficients of variation (CV) were 2.6% for medial and 2.0% for lateral cartilage volume. Maximal medial and lateral tibial cartilage thickness was measured using calipers with CV of 2.2% and 2.3%[5]. Medial and lateral tibial plateau areas were determined by creating an isotropic volume from the input images that was reformatted in the axial plane. Areas were directly measured from these images as described[5]. CV were 2.3% for medial and 2.4% for lateral tibial plateau areas[5].

Cartilage volume is presented as ml cartilage per cm^2 in order to adjust the amount of cartilage for bone size, which has been shown to be an

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important determinant of cartilage volume[4,5]. Paired t tests were used for comparison of medial and lateral tibial cartilages. Linear regression was used to examine the effect of age, sex, BMI, and bone area on cartilage volumes in univariate and multivariate models. Results are presented as regression coefficients representing differences in cartilage volume per unit change in the relevant explanatory factor, while other factors are controlled for.

RESULTS

In this study, 58% of subjects were female, with an age range of 24 to 76 years (mean 52.2 ± 10), an average BMI of 25.6 ± 5.9 kg/m^2, and average total physical activity score 7 ± 2. In every subject, the lateral tibial articular cartilage was thicker and of greater volume than the medial (6.43 ± 1.25 vs 4.49 ± 0.81 mm, $p < 0.001$; 2.34 ± 0.70 vs 1.82 ± 0.56 ml, $p < 0.001$, respectively) (Table 1). These differences persisted when women and men were examined separately (Table 1).

The main determinant of both tibial cartilages was bone size as measured by the area of the tibial plateau — 12.5% (partial r^2) for lateral cartilage and 12.8% for medial cartilage. Lateral tibial plateau area was smaller than the medial tibial plateau area in all cases (25.00 ± 26.34 vs 16.59 ± 17.38 cm^2). Cartilage volume in Table 2 is presented as ml cartilage per cm^2 tibial bone area, to take into account the differences in bone size between the medial and lateral tibia. Men had significantly more cartilage than women in both the medial and lateral compartments after adjusting for age, BMI, and physical activity score. The current level of physical activity was associated with a lower cartilage volume in both compartments.

DISCUSSION

This cross sectional study showed that knee cartilage is thicker and of larger volume in the lateral compared to the medial tibiofemoral compartment in healthy adults. Similar changes were seen when men and women were examined separately. Both medial and lateral tibial cartilage volumes were significantly affected by male sex and bone size. BMI and current level of physical activity were inversely associated with both cartilage volumes.

Greater lateral versus medial cartilage thickness and volume has recently been reported in both male and female children[5]. Our results suggest these differences persist into adulthood in both males and females. The reason for increased knee cartilage in the lateral compartment compared to the medial tibiofemoral compartment is

Table 1. Comparison of knee compartment cartilage.

	Lateral, mean (SD)	Medial, mean (SD)	Difference (95% CI)	p for Difference
Maximum cartilage thickness, mm				
All subjects, n = 166	6.43 (1.25)	4.49 (0.81)	1.94 (1.78, 2.11)	< 0.001
Females, n = 96	5.96 (0.99)	4.17 (0.60)	1.82 (1.60, 1.98)	< 0.001
Males, n = 70	7.13 (1.26)	5.00 (0.86)	2.15 (1.80, 2.46)	< 0.001
Total cartilage volume, ml				
All subjects, n = 166	2.34 (0.70)	1.82 (0.56)	0.51 (0.45, 0.58)	< 0.001
Females, n = 96	1.95 (0.39)	1.55 (0.33)	0.40 (0.34, 0.46)	< 0.001
Males, n = 70	2.94 (0.67)	2.24 (0.59)	0.70 (0.57, 0.83)	< 0.001

Table 2. Determinants of medial and lateral tibial cartilage volumes.

	Univariate Analysis, Regression Coefficient	Multivariate Analysis*, Regression Coefficient	95% CI	p
Medial tibial cartilage, ml/cm^2**				
Age[1]	–0.001	–0.001	–0.005, 0.0031	0.97
Sex	0.22	0.200	0.10, 0.30	0.000
Body mass index[2]	–0.003	–0.008	–0.018, 0.002	0.11
Physical activity[3]	–0.038	–0.035	–0.062, –0.008	0.01
Lateral tibial cartilage, ml/cm^2				
Age[1]	–0.001	–0.001	–0.006, 0.005	0.80
Sex	0.23	0.21	0.05, 0.37	0.009
Body mass index[2]	–0.013	–0.018	–0.033, –0.003	0.11
Physical activity[3]	–0.035	–0.04	–0.08, 0.000	0.05

* Multivariate analysis with age, BMI, and physical activity in regression equation. ** Cartilage volume expressed as ml/cm^2 of corresponding tibial plateau area. [1] Change per 1 year increase in age. [2] Change per unit increase in BMI. [3] Change per unit increase in physical activity score. Total activity is a composite score of total amount of walking (0–4) + activity at home (0–4) + sporting activity (0–4).

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unknown. During walking, the weight of the body is medial to the knee, resulting in a compressive force on the medial aspect and a stretching force on the lateral aspect of the knee[8]. Thus one may expect thicker cartilage in the medial compartment, as seen in the bovine knee[9] and in beagles[10], with loading patterns similar to humans. Why cartilage is not thicker medially in humans is unclear. However, consistent with our findings, a recent study of 11 human cadavers has suggested an inverse relation between the mean cartilage thickness and mean compressive modulus in the lower limb joints[11].

Our group and others have described sex effects on knee cartilage[4,12-14]. However, the effects of BMI and physical activity are less clear. In a study of 11 cadavers, the mass of specimen donors was found to correlate with mean knee cartilage thickness[11]. Another study showed a correlation between knee cartilage thickness and body weight in men[13]. In healthy children, we showed that physical activity was associated with an increase in knee cartilage[5]. However, in a small study of adults, the mean and maximal knee cartilage thicknesses, although not statistically significant, were lower in the medial femoral condyle and in the medial and lateral tibial plateau in 11 triathletes compared to physically inactive volunteers[15]. It may be that the effect of physical activity on knee cartilage differs in adults and children.

There are a number of potential limitations in using MRI for cartilage estimates. The accurate delineation of articular cartilage depends on high contrast relative to adjacent tissues. Our method has been validated against cadavers[4] and has excellent reproducibility, with coefficients of variation of 2–3% that compare very favorably to the magnitude of the differences reported. Further, in order to improve in-plane resolution we used a matrix of 512 × 512 pixels, resulting in an in-plane resolution of 0.31 × 0.31.

This study supports the knee compartment differences in knee cartilage volume recently reported in children. It is likely these differences are maintained throughout life. The possibility that the amount of knee cartilage in an individual is a risk factor for OA now needs to be tested in longitudinal studies.

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