

Tibial Plateau Cartilage Thickness during Skeletal Growth in Porcine Knees

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INTRODUCTION: Adult human in-vivo models and skeletally mature animal models have demonstrated that tibial plateau cartilage is thicker in areas uncovered by the meniscus, and tibial plateau cartilage covered by the meniscus experiences lower strain and decreased degradation, suggesting a protective effect of the meniscus on cartilage health (1, 2). However, it remains unknown how tibial plateau cartilage changes and adapts during normal skeletal growth. Understanding the progression of cartilage thickness during skeletal growth provides important insight into the impact of early joint loading on cartilage in skeletally immature models. The objective of this study was to evaluate age-related changes in tibial plateau cartilage thickness during skeletal growth in Yorkshire crossbreed pigs. It was hypothesized that tibial plateau cartilage would decrease in thickness with increasing age, and that tibial plateau cartilage covered by meniscus would experience a larger decline in thickness than uncovered cartilage.

METHODS: Magnetic resonance imaging (MRI) datasets of stifle (knee) joints were obtained for 40 Yorkshire pigs (20 female, 20 male) at 1.5, 3, 4.5, and 18 months of age (n=5 per sex and age group). The age groups represent various levels of skeletal maturity, with 18 months indicating skeletal maturity in porcine knees (3). MRI was performed on a 3T Siemens MAGENTOM Skyra MRI system using a double echo steady state scan sequence, and three-dimensional (3D) geometric models of the tibial plateau cartilage were created by segmenting the MRI images using MIMICS (v23). A custom MATLAB code (v2023b) was then utilized to measure and plot cartilage thickness across each model of the tibial plateau cartilage (Figure 1). Each tibial plateau cartilage model was split into regions covered and uncovered by the meniscus using previous anatomical measurements of porcine medial and lateral menisci width relative to tibial plateau width (4). The four regions were defined as: covered lateral (lateral plateau covered by meniscus), covered medial (medial plateau covered by meniscus), uncovered lateral, and uncovered medial. Following normality testing, Spearman correlations (ρ) were utilized to determine the association between age and cartilage thickness in all tibial plateau regions. The cartilage thickness of each tibial plateau region at 18 months was then compared to the average thickness of each region at 1.5 months to determine percent change in thickness during growth, and compared using a one-sample t-test. Significance was set to $p < 0.050$.

RESULTS:

Significant changes in tibial plateau cartilage thickness were observed based on age and tibial plateau region. In males, a significant negative correlation was found between age and tibial plateau cartilage thickness in the covered lateral ($\rho = -0.934$; $p < 0.001$), covered medial ($\rho = -0.923$; $p < 0.001$), and uncovered lateral ($\rho = -0.667$; $p = 0.001$) regions (Figure 2). No correlation was found between age and tibial plateau cartilage thickness in the uncovered medial region ($\rho = -0.098$; $p = 0.681$) (Figure 2). The percent change in tibial plateau cartilage thickness between 1.5 months and 18 months was 53.1% decrease in covered lateral ($p < 0.001$), 45.2% decrease in covered medial ($p < 0.001$), 35.1% decrease in uncovered lateral ($p < 0.001$), and 1.4% increase in uncovered medial ($p = 0.808$) regions. In females, similar correlations were identified with a significant negative correlation between age and tibial plateau cartilage thickness in the covered lateral ($\rho = -0.952$; $p < 0.001$), covered medial ($\rho = -0.919$; $p < 0.001$), and uncovered lateral ($\rho = -0.733$; $p < 0.001$) regions, as well as no correlation between age and tibial plateau cartilage thickness in the uncovered medial region ($\rho = -0.267$; $p = 0.256$) (Figure 2). The percent decrease in tibial plateau cartilage thickness between 1.5 months and 18 months for females was 50.4% decrease in covered lateral ($p < 0.001$), 42.4% decrease in covered medial ($p < 0.001$), 31.2% decrease in uncovered lateral ($p < 0.001$), and 9.6% decrease in uncovered medial ($p = 0.076$).

DISCUSSION: The main finding of the study was that tibial plateau cartilage thickness significantly decreased in the covered lateral, covered medial, and uncovered lateral regions during skeletal growth, whereas tibial plateau cartilage thickness did not decrease significantly in the uncovered medial region. The overall decrease in tibial plateau cartilage thickness during skeletal growth may be attributed to the conversion of immature cartilage to bone during endochondral ossification (5). Another plausible explanation is that overall cartilage volume remains preserved across skeletal growth, but undergoes a decrease in thickness due to the increasing area of the tibial plateau during growth. However, the larger decline in tibial plateau cartilage thickness observed in covered versus uncovered regions may indicate preferential cartilage growth in uncovered regions due to the protective effect of the meniscus with respect to load distribution and stress across the joint (6,7). In addition, the decreased cartilage stress underneath the meniscus may favor region-specific endochondral ossification while approaching skeletal maturity, further contributing to decreases in cartilage thickness underneath the meniscus.

SIGNIFICANCE/CLINICAL

RELEVANCE: Understanding the natural progression of tibial plateau cartilage maturation during skeletal growth with respect to the meniscus provides a framework for further investigation into the impact of repetitive axial loading on cartilage maturation during skeletal growth.

REFERENCES: (1) Liu et al, AJSM 2017; (2) Thambayah et al, Osteoarthritis Cartilage 2006; (3) Cone et al, PLOS One 2019; (4) Mungalpara et al, The Knee 2024; (5) Mackie et al, Int J Biochem Cell Biol 2007; (6) Verdonk et al, KSSTA 2016; (7) McCann et al, Osteoarthritis Cartilage 2009

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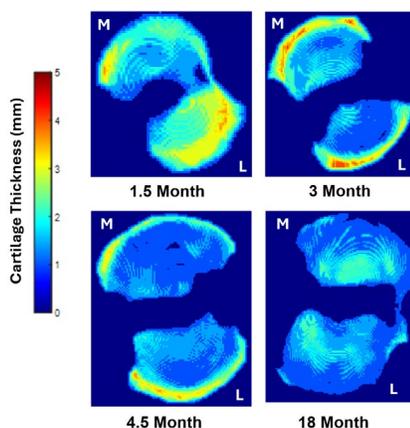


Figure 1. Example Female Porcine Tibial Plateau Cartilage Models Showing Cartilage Thickness at 1.5, 3, 4.5, and 18 Months. M = medial, L = lateral.

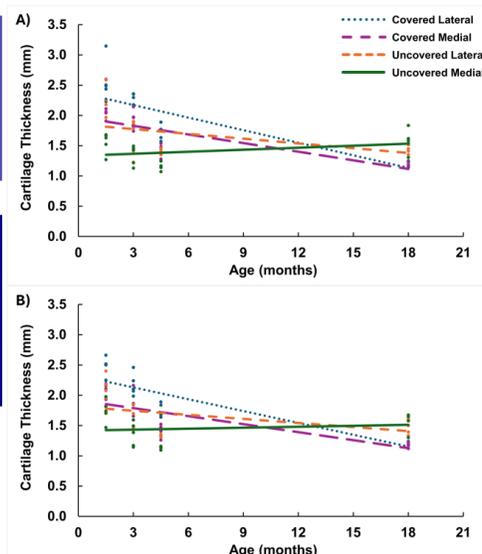


Figure 2. Tibial Plateau Cartilage Thickness based on Age and Region in A) Male and B) Female Porcine Knees