

Anatomical Variation of Depth-dependent Shear Mechanics of Human Knee Cartilage

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INTRODUCTION: Cartilage has a depth-dependent architecture with specific organization of its components that appear as distinct zones: surface, middle, and deep. Each possesses unique mechanical properties and biochemical composition that give cartilage its overall function. Within the knee joint cartilage varies anatomically, each region having different compressive loads¹, shear modulus², thickness, and permeability¹. Although it is known that tissues from low weight-bearing regions (trochlea) are stiffer in tension than those from the high weight-bearing region³ (femoral condyle). It has been found very complaint shear mechanics within the first 500 μm of the tissue surface in bovine patella, patellofemoral groove, tibia, and femoral condyle². However, there's little knowledge of the depth-dependent shear mechanics between the patella, trochlea, tibia, and femoral condyle within the human knee joint. I hypothesize that patella will have the lowest shear mechanics while condyles will have the highest shear mechanics. The objective of this study was to compare depth-dependent mechanical properties of the patella, trochlea, tibia, and femoral condyle of human knee cartilage.

METHODS: Human knee joints were obtained from the Hospital for Special Surgery as operation room discards from patients undergoing osteochondral allograft (OCA). OCA tissues were provided by JRF Ortho (Englewood, CO) from cadaveric donors aged 14 to 28 after consent for research use. Articular cartilage plugs (6mm diameter and 2mm height) were obtained from the femoral condyle (n=10), tibia (n=4), trochlea (n=3), and patella (n=9). The tested samples were six male and four female. Depth-dependent shear mechanics of the samples were tested following by an established protocol and custom MATLAB code⁴. The samples were compressed with 15% tissue thickness and 1% peak shear. The strain data were fitted into a sinusoidal function and stress was calculated from the force applied by the stationary plate to the cross-section of the tissue. The final shear modulus (G^*) was calculated by dividing the depth-dependent shear strain by constant shear stress. The G^* min is the minimum the modulus reached and the G^* plateau was calculated once the tissue modulus no longer increased at a depth greater than 1000 μm .

RESULTS: The shear strain data showed the anatomical variations in which the patella has the highest shear strain for the first 200 μm , followed by tibia, trochlea and femoral condyle (Fig 1A). The patella showed a shear modulus that is an order of magnitude lower than the trochlea, tibia, and femoral condyle (Fig 1B). The patella had very low G^* min ($p < 0.0001$) compared to femoral condyle and the rest of the groups (Fig 1C). The G^* plateau showed the shear modulus of the sample didn't increase after 1000 μm for both trochlea and tibia ($p = 0.9042$). When compared to patella, femoral condyle had higher G^* plateau ($p < 0.000$) followed by trochlea ($p < 0.0001$) and tibia ($p < 0.0001$) (Fig 1D).

DISCUSSION: The only significance was observed between the patella and the other three locations, thus showing that the patella doesn't experience high compressive and shear forces compared to the femoral condyle, trochlea and tibia. It is notable that tissues that experience low weight bearing (patella and trochlea) have low shear modulus while tissue that experiences high weight bearing is shown to have a higher shear modulus.

SIGNIFICANCE: This study investigated depth-dependent shear mechanics in different anatomical locations of human knee cartilage. The study showed that low-weight-bearing locations of the knee have the lowest shear mechanics (patella) while high-weight-bearing parts of the knee showed to have high shear modulus. This study will provide important information about the relationship of mechanics and anatomical variations of human knee cartilage; thus, benefiting future OCA surgeries, OA therapeutics and tissue-engineered cartilage.

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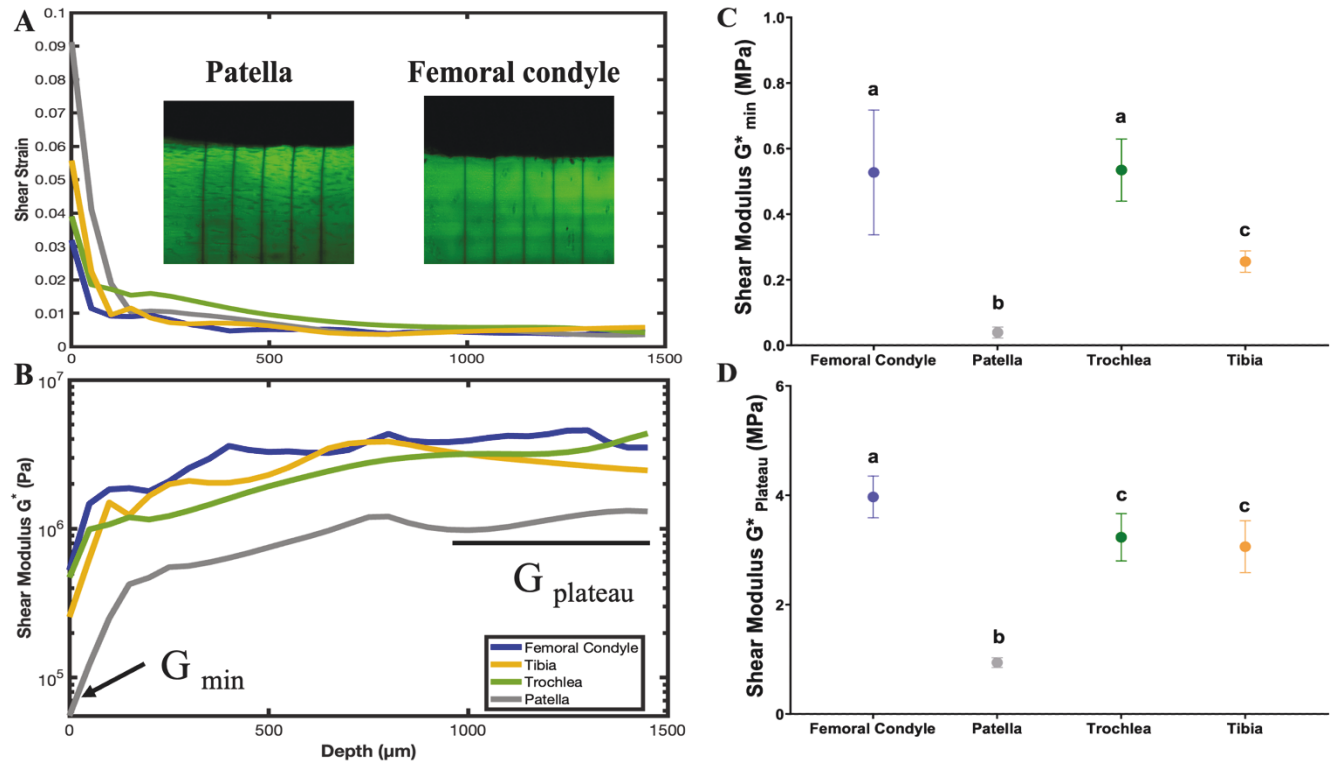


Figure 1: A: Depth-dependent shear strain showed higher strain for patella B: Depth-dependent shear modulus for the groups. C: Shear modulus minimum showed patella has the lowest mechanics. D: Shear modulus plateau for all the groups showed high weight-bearing areas have similar G^* plateau. Groups that have different letters denote significance ($p < 0.05$). The data shown is mean \pm standard deviation. Analyzed using 1-way ANOVA with Tukey's multiple comparison test.