Osteoarthritis-Related 3D Microstructural Changes in Tibial and Patellar Groove Subchondral Bone: Bone Volume Increase, Connectivity Density Decrease, and Patellar Groove Perimeter Widening

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INTRODUCTION: Numerous studies have extensively described the tibial plateau 3D microstructural changes in subchondral bone in knee osteoarthritis (OA), such as elevated bone volume fraction (BV/TV) and trabecular thickness (Tb.Th), but reduced trabecular separation (Tb.Sep). However, the literature presents conflicting or limited findings regarding the specific involvement of other subchondral bone microstructural parameters in tibial plateau knee OA progression. Additionally, the patellar groove (PG) remains vastly under-explored in comparison to the tibial plateau. No human studies have directly quantified the microstructure of the PG in knee OA. This study aimed to clarify microstructural changes present in the tibial plateau in knee OA, and to identify if similar microstructural changes that have been described in the tibial plateau also occur in the PG to support the model of whole knee change in knee OA.

METHODS: PG and tibial plateau samples were collected unilaterally from 20 cadavers in the NYITCOM anatomy lab, analyzed via microCT, and imported into Dragonfly for segmentation of cortical and trabecular bone. From the Dragonfly segmentation, 23 quantitative parameters were calculated within volumes of interest defined as cylinders with dimensions of 5mm radius, 7.5mm depth in 5 locations: the medial tibia, lateral tibia, medial PG, lateral PG, and central PG. Following calculations, tibial plateau and PG data were divided into groups based on three independent thresholds as OA vs. non-OA: BV/TV > 0.4, Tb.Th > 0.325 mm, and Tb.Sep < 0.6 mm (thresholds were defined by averaging the results of 3 papers discussing the microstructural parameters of the tibial plateau in knee OA). This gives 15 dataset comparisons to be made, given 5 locations and 3 thresholds. Shapiro-Wilks tests, paired T-tests, and Mann-Whitney U tests were conducted on all 23 parameters. These calculated parameters are associated with each threshold and location (15 dataset comparisons on 23 parameters, giving 345 individual calculations).

RESULTS: For the tibial plateau, when thresholding by BV/TV, there was a significant increase in Tb.Th, periosteal surface, cortical thickness, cortical area fraction, cortical porosity, and bone volume (BV), accompanied by a decrease in Tb.Sep, structure model index (SMI), and average marrow area. When thresholding by Tb.Th, there were increases in BV/TV, trabecular number (Tb.N), BV, cortical area fraction, cortical porosity, and cortical thickness, but decreases in specific bone surface, connectivity density, marrow area, SMI, and total cortical & marrow area. When thresholding by Tb. Sep, there were increases in anisotropy, cortical area fraction, periosteal perimeter, periosteal surface, Tb.N, but decreases in bone surface density and bone surface. For the PG, when thresholding by BV/TV, there were significant increases in endocortical perimeter, endocortical surface, periosteal surface, Tb.N, Tb.Th, Tb.Sep, and BV, but decreases in specific bone surface, connectivity density, and cortical porosity. When thresholding by Tb.Th, there were significant increases in bone surface density, BV/TV, cortical area fraction, Tb.Th, bone surface, and BV, but decreases in connectivity density and cortical porosity (note, Tb.N had significant differences, but was excluded because of inverse directionality in PGM and PGL). When thresholding by Tb.Sep, there were increases in cortical porosity, endocortical perimeter, endocortical surface, and Tb.N, but decreases in Tb.Sep.

DISCUSSION: In 8 of the 15 comparisons across the knee joint, increased BV was found. In 6 out of 15, decreased connectivity density was found. In 4 of the comparisons made within the PG specifically, endocortical perimeter or periosteal perimeter is increased, suggesting that OA could be associated with increased total PG perimeter. Firstly, similar findings across multiple locations within the knee joint strongly support the model of whole knee change in knee OA. Secondly, this study highlights the involvement of the PG in knee OA. Increases in periosteal and endocortical perimeters in the PG could indicate compensatory modeling in the cortical shell, potentially reflecting altered load transfer through the patellofemoral joint. This could also reflect an adaptive mechanism to counteract trabecular loss of connectivity density and rising BV in knee OA, which points towards a larger but less connected bone.

SIGNIFICANCE/CLINICAL RELEVANCE: This study further expands upon our understanding of the pathophysiology of OA - one of the most prevalent joint diseases affecting millions globally. Our project presents foundational information on the progression of knee OA that can ultimately lead to advancements in treatment options and more effective preventive strategies for patients.

Table 1. 23 quantitative parameters calculated across 5 knee joint locations, using 3 separate thresholds for each location: BV/TV, Tb.Th, and Tb.Sep.. MT=medial tibia, LT=lateral tibia, MPG = medial patellar groove, LPG= lateral patellar groove, CPG= center patellar groove. T-tests or Mann-Whitney U Tests compared the OA group to the non-OA group for each joint location and quantitative parameter. Values are reported as significance (power level). Alpha=.05. Significant results are bolded.

	MT (BV/TV)	MT (Tb.Th)	MT (Tb.Sep)	LT (BV/TV)	LT (Tb.Th)	LT (Tb.Sep)	MPG (BV/TV)	MPG (Tb.Th)	MPG (Tb.Sep)	LPG (BV/TV)	LPG (Tb.Th)	LPG (Tb.Sep)	CPG (BV/TV)	CPG (Tb.Th)	CPG (Tb.Sep)
Anisotropy (MIL)	0.866 (35)	0.968 (43)	0.718 (47)	0.633 (46)	1.000 (39)	0.878 (30)	0.899 (-0.131)	0.599 (-0.558)	0.932 (-0.088)	0.214 (8)	1.000 (14)	0.589 (14)	0.530 (13)	0.808 (14)	0.600 (17)
Anisotropy (SVD)	0.181 (-1.426)	0.280 (-1.119)	**0.011 (2.862)**	0.266 (53)	0.525 (46)	0.079 (45)	0.389 (-0.901)	0.214 (-1.356)	0.477 (0.745)	0.720 (-0.370)	0.907 (0.126)	0.487 (0.725)	0.841 (-0.211)	0.527 (0.685)	0.937 (-0.088)
Specific bone surface	0.177 (-1.519)	**0.001 (-4.406)**	0.672 (-0.439)	0.122 (22)	0.179 (23)	0.645 (33)	0.332 (-1.067)	0.778 (-0.289)	0.816 (0.241)	0.073 (5)	0.482 (9)	0.485 (13)	**0.037 (-2.410)**	0.114 (-1.752)	0.747 (0.347)
Bone surface density	0.406 (0.882)	0.270 (-1.180)	**0.004 (-3.354)**	0.633 (34)	0.724 (43)	0.327 (18)	0.759 (0.320)	0.334 (1.025)	0.741 (0.346)	0.322 (1.045)	**0.022 (2.709)**	0.305 (1.132)	0.989 (0.015)	0.789 (-0.277)	0.307 (1.084)
Bone volume fraction	N/A	**0.014 (3.030)**	0.143 (-1.653)	N/A	**0.002 (3.725)**	0.255 (-1.335)	N/A	**0.010 (3.312)**	0.965 (0.045)	N/A	**0.036 (25)**	0.132 (28)	N/A	**0.013 (3.233)**	0.965 (0.048)
Connectivity density	0.387 (-0.941)	**0.042 (-2.379)**	0.158 (-1.563)	0.138 (-1.606)	**0.031 (-2.399)**	0.232 (-1.402)	**0.033 (-2.588)**	**0.003 (-4.061)**	0.490 (0.717)	0.591 (-0.574)	**0.001 (-6.376)**	0.647 (0.473)	**0.024 (-2.872)**	**0.012 (-3.302)**	0.161 (-1.928)
Cortical area	0.734 (0.358)	0.706 (0.392)	0.866 (-0.173)	0.405 (0.869)	0.912 (-0.112)	0.257 (-1.319)	0.134 (1.663)	0.080 (1.953)	0.512 (-0.689)	0.109 (26)	0.100 (23)	0.485 (23)	0.907 (0.121)	0.586 (0.586)	0.908 (0.124)
Cortical area fraction	0.447 (0.797)	0.491 (0.709)	0.314 (1.087)	**0.034 (64)**	**0.015 (65)**	**0.046 (9)**	0.106 (28)	0.091 (27)	0.343 (11)	0.274 (1.176)	**0.018 (26)**	0.961 (0.050)	0.436 (0.814)	0.512 (0.683)	0.226 (-1.663)
Cortical porosity	1.000 (37)	0.718 (37)	0.547 (34)	**0.027 (65)**	**0.085 (58)**	0.442 (20)	**0.014 (-2.989)**	0.056 (-2.466)	0.846 (-0.199)	0.902 (-0.128)	**0.117 (-1.996)**	0.468 (0.758)	0.807 (19.5)	0.733 (13.5)	**0.016 (27)**
Average cortical thickness	0.553 (45)	0.904 (44)	0.353 (54)	**0.026 (2.706)**	0.059 (2.086)	0.959 (0.053)	0.112 (1.747)	0.424 (0.859)	0.921 (-0.102)	0.364 (0.987)	0.113 (1.911)	0.661 (0.453)	0.528 (0.670)	0.730 (-0.361)	0.793 (0.294)
Endocortical perimeter	0.958 (-0.056)	0.788 (0.278)	0.561 (0.611)	0.573 (33)	0.479 (30)	0.505 (21)	0.432 (12)	0.229 (-1.302)	0.934 (-0.085)	**0.048 (28)**	0.209 (21)	**0.041 (31)**	0.350 (-0.998)	0.448 (-0.835)	0.159 (1.719)
Endocortical surface (3D)	0.230 (52)	0.239 (57)	0.444 (32)	0.762 (44)	1.000 (38)	0.327 (18)	0.953 (-0.063)	0.505 (-0.692)	0.715 (0.376)	**0.072 (2.017)**	0.269 (1.182)	0.318 (1.052)	0.219 (-1.396)	0.198 (-1.584)	**0.046 (2.279)**
Marrow area	0.933 (39)	0.779 (38)	0.312 (29)	**0.002 (-3.637)**	**0.015 (-2.748)**	0.863 (0.184)	0.202 (9)	0.368 (10)	0.876 (16)	0.214 (24)	0.246 (1.261)	0.120 (1.726)	0.596 (-0.551)	0.925 (0.098)	0.482 (18)
Periosteal perimeter	0.943 (-0.075)	0.813 (-0.246)	0.677 (0.433)	0.360 (51)	0.246 (52)	**0.012 (5)**	0.206 (1.472)	0.154 (1.560)	0.834 (-0.219)	0.154 (25)	0.145 (22)	0.180 (27)	0.737 (-0.349)	0.684 (-0.435)	0.093 (1.860)
Periosteal surface (3D)	0.060 (2.098)	0.101 (1.763)	0.873 (-0.164)	0.173 (56)	0.211 (53)	**0.025 (7)**	**0.030 (31)**	0.105 (1.871)	0.864 (-0.176)	0.214 (24)	0.727 (16)	0.394 (24)	1.000 (17)	0.368 (10)	0.600 (17)
Structure model index	0.168 (21)	0.547 (34)	0.130 (61)	**0.001 (-4.207)**	**0.006 (-3.226)**	0.281 (1.278)	0.158 (-1.528)	0.479 (-0.783)	0.352 (-0.981)	0.683 (13)	0.727 (11)	0.485 (13)	0.733 (-0.353)	0.836 (0.214)	0.574 (0.616)
Trabecular number	0.395 (27)	**0.012 (12)**	0.312 (29)	0.696 (45)	0.724 (34)	**0.001 (1)**	0.326 (-1.085)	**0.038 (-2.397)**	**0.025 (2.633)**	0.073 (2.012)	0.830 (-0.226)	**0.001 (5.093)**	1.000 (18)	0.683 (13)	**0.009 (27)**
Trabecular separation	**0.029 (-2.602)**	0.300 (-1.078)	N/A	0.073 (-1.945)	0.328 (-1.027)	N/A	0.143 (-1.266)	N/A	**0.001 (-5.474)**	**0.048 (4)**	N/A	0.689 (-0.417)	0.127 (-1.677)	N/A	0.064 (3)
Trabecular thickness	**0.019 (64)**	N/A	0.841 (39)	**0.002 (73)**	N/A	0.233 (16)	**0.010 (33)**	**0.004 (32)**	N/A	0.268 (1.223)	0.482 (9)	N/A	**0.010 (33)**	0.437 (-0.818)	N/A
Cortical + marrow area	0.735 (42)	1.000 (42)	0.444 (32)	0.120 (-1.672)	**0.005 (-3.276)**	0.853 (-0.198)	0.876 (16)	0.808 (14)	0.876 (19)	0.109 (26)	0.373 (19)	0.065 (30)	0.760 (-0.314)	0.773 (0.300)	0.456 (0.877)
Bone surface	0.404 (0.890)	0.383 (-0.917)	**0.006 (-3.258)**	0.898 (-0.133)	0.588 (0.553)	0.391 (-0.884)	0.754 (0.328)	0.423 (0.843)	0.608 (0.544)	0.238 (1.272)	**0.029 (2.566)**	0.273 (1.226)	0.199 (-1.430)	0.210 (-1.492)	0.879 (0.157)
Bone volume	**0.001 (4.644)**	**0.003 (3.780)**	0.167 (-1.527)	0.106 (1.818)	**0.018 (2.678)**	0.413 (-0.898)	**0.002 (4.816)**	**0.019 (2.817)**	0.759 (0.316)	**0.024 (3.642)**	0.085 (2.788)	0.090 (1.973)	**0.004 (3.775)**	**0.042 (2.340)**	0.950 (0.069)
Total volume	0.472 (0.739)	0.132 (1.682)	0.891 (0.140)	0.237 (26)	0.246 (25)	0.878 (30)	0.923 (0.102)	0.309 (-1.072)	0.198 (1.382)	0.808 (14)	1.000 (14)	0.589 (22)	0.530 (13)	0.283 (9)	0.727 (16)

	BV/TV	Tb.Th	Tb.Sep
Medial Tibia			
Lateral Tibia			
Medial PG			
Central PG			
Lateral PG			