Computed Tomography Topographical Mapping of Bone Density (CT-TMoBD) in Osteoarthritic and Normal Knees: Preliminary Results

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Materials and Methods: We developed a novel imaging tool: CT-TMoBD (computed tomography topographic mapping of bone density), which employs a surface projection imaging method to map both 3D subchondral thickness and density at the joint surface. This imaging technique computes the average bone density to defined depths from the subchondral bone surface, and projects results to a 2D topographic thickness/density map in a selected plane (Figure 1). Eight intact fresh-frozen cadaver knees from five donors (4M:1F; mean age: 69±12) were CT scanned (Toshiba Aquilion 64, 0.5mm isotropic voxel) and a bone density reference phantom (Mindways) was used to convert CT intensity to an equivalent volumetric bone mineral density (BMD) (mg/cm³ K₂HPO₄). The proximal tibia was manually segmented in the sagittal plane using Analyze 6.0 (Mayo Foundation). To account for differences in size, relative volume measures of the proximal tibia were obtained (volume superior to the lateral inferior ridge of the proximal fibular head). 3D boundary points outlining the peripheral and inner regions of each plateau were manually selected within Analyze, and best-fit planes were matched to the respective boundary points (Mathlab 2007a). Tibial plateaus were realigned relative to the best-fit planes. Surface projections of the average BMD to normalized depths of 2.5mm and 5.0mm were mapped to 2D images of the joint surface (depths normalized according to proximal tibial volume). Specific depths were selected as only subchondral and trabecular bone within 5.0mm of the subchondral surface offer resistance to mechanical loading [2] and density changes within 2-3mm of the subchondral surface are capable of adversely affecting the overlying cartilage [3]. Surface projections for the medial and lateral plateaus were manually segmented using the previously defined boundary points. Regional analyses were performed on each surface map, including: (a) Total average BMD of both the medial and lateral plateaus combined, (b) average BMD of each plateau, (c) Anterior / Central / Posterior compartment BMD; assessed by dividing the plateaus into three equal height compartments partitioned relative to the long axes of the plateau segmentations, and (d) average BMD of a 10mm diameter 'core' which searched each plateau for a max value. Each knee was assessed for OA by a surgeon using fluoroscopic radiographic evidence of osteophytes and sclerosis via Kellgren-Lawrence (KL) scoring and visual examination of the CT images.

Results: We identified OA in three compartments of two knees using radiography and standard CT. CT images showed that knee OA1 was in valgus alignment and showed osteophytes and sclerosis in the lateral compartment, while medially osteophytes were evident though sclerosis was not. Knee OA2 was in varus alignment and showed medial sclerosis and osteophyte presence. KL scoring identified OA only in knee OA1 (KL grade 3). In the valgus aligned specimen (OA1), lateral plateau BMD (5mm depth) was 31% higher than medial plateau BMD, in contrast with normals, where medial and lateral BMD were similar (Table 1, Figure 1). The peak core in this knee was found in the lateral compartment and BMD of the peak core was 3.7 standard deviations higher than that of normals (Table 1, Figure 1). In the varus aligned specimen (OA2), medial plateau BMD was 46% higher than lateral plateau BMD. The peak core in this knee was found in the medial compartment and BMD of the peak core was 2.5 standard deviations higher than that of normals.

Discussion: The CT-TMoBD method is capable of characterizing subchondral bone density distribution in relation to thickness measures in osteoarthritic and normal subjects, and can offer additional information to the CT-OAM maximum density projection method [1]. Our early results show substantial differences in subchondral BMD patterns between OA and normals that are consistent with knee malalignment. The method has potential to identify and quantify changes in subchondral bone mineral density that may be associated with osteoarthritis disease progression.

Table 1: Average bone mineral density measures (K₂HPO₄) in osteoarthritic and normal cadaver knees

<table>
<thead>
<tr>
<th>Depth</th>
<th>Osteoarthritic</th>
<th>Normal</th>
<th>Osteoarthritic</th>
<th>Normal</th>
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<tbody>
<tr>
<td>2.5mm</td>
<td>409</td>
<td>423</td>
<td>381</td>
<td>379</td>
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<tr>
<td>5.0mm</td>
<td>377</td>
<td>390</td>
<td>386</td>
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