Stiffness of the proximal tibial bone in osteoarthritic conditions: a parametric simulation study

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INTRODUCTION
Osteoarthritis (OA) is a painful, debilitating joint disease marked by cartilage degeneration and underlying subchondral bone changes [1]. To date, the exact mechanism of OA initiation and progression is unclear [2]. One predominant theory indicates that observed increased quantity and stiffness of bone near the subchondral surface results in an overall stiffer subchondral bone, which will change the load distribution in cartilage layer leading to OA [3]. However, other OA studies have found decreased amounts of bone at sites distal to the subchondral bone surface (>5 mm), which may also alter subchondral bone stiffness and cartilage load distribution. Using parametric finite element (FE) modeling, the objective of this study was to investigate the relative effects of varying proximal tibial morphologic and mechanical bone properties on overall subchondral bone stiffness.

METHODS
Normal and OA related mechanical properties and geometry of different layers of the proximal tibia were chosen based on literature (Table 1) [4-8]. The overall geometry of the model was based on a segmented (ANALYZE, Mayo Foundation) CT image of a cadaveric proximal tibia (~100 mm distal to the tibio-femoral joint line). The segmented geometry was simplified to develop a 2D, symmetric, plane-strain, FE model of proximal tibia (1096 PLANE42 elements, 8 different material properties) using ANSYS (ANSYS Inc.) (Figure 1).

![Figure 1](image)

Figure 1 Different layers of the symmetric FE model of the proximal tibia. (SC: Subchondral Cortical, ST: Subchondral Trabecular, ET: Epiphysial Trabecular).

In this model, varied bone properties included subchondral cortical thickness (SCT) and stiffness (elastic modulus) (SCS), subchondral trabecular thickness (STT) and stiffness (STS) and epiphysial trabecular stiffness (ETS). Normal values for SCT, STT and ET thickness were chosen to be 1, 2.5 and 15 millimeters, respectively [4-7]. Normal SCS, STS and ETS were 1000, 500 and 300 MPa, respectively [4,10]. For each set of analysis, four parameters were set at normal values while one parameter was altered within a range of values observed with OA. “Effective Stiffness (K)” was defined as the overall stiffness of the proximal tibia, calculated using nodal displacement and load of the loading area on subchondral cortical bone surface. For this analysis we report K, expressed relative to normal stiffness (Knorm) following either a 20% increase or 20% decrease of each parameter. The ±20% variation is selected based on literature [9] and is considered as a reasonable properties alteration in OA condition.

RESULTS
The results of FE analysis are presented in Table 1. The normal Knorm of 22.63 MN/m was calculated using the normal values of all parameters. Changing ETS had the largest influence on subchondral bone stiffness, resulting in a change of 0.2 Knorm with a 20% reduction in stiffness. All other 4 parameters affected K by less than 2%, even considering their minimum and maximum possible values.

Table 1: Effect of altering each parameter on overall stiffness of the proximal tibial model. K/Knorm represents the change in K following ±20% variation of each parameter, with respect to its normal value (Knorm).

<table>
<thead>
<tr>
<th>Param.</th>
<th>Norm.</th>
<th>-20%</th>
<th>K/Knorm</th>
<th>+20%</th>
<th>K/Knorm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCT</td>
<td>1 mm</td>
<td>0.8 mm</td>
<td>0.99</td>
<td>1.2 mm</td>
<td>1.01</td>
</tr>
<tr>
<td>STT</td>
<td>2.5mm</td>
<td>2 mm</td>
<td>0.99</td>
<td>3 mm</td>
<td>1.01</td>
</tr>
<tr>
<td>SCS</td>
<td>1000MPa</td>
<td>800MPa</td>
<td>0.99</td>
<td>1200MPa</td>
<td>1.01</td>
</tr>
<tr>
<td>STS</td>
<td>500MPa</td>
<td>400MPa</td>
<td>0.99</td>
<td>600MPa</td>
<td>1.01</td>
</tr>
<tr>
<td>ETS</td>
<td>300MPa</td>
<td>240MPa</td>
<td>0.80</td>
<td>360MPa</td>
<td>1.17</td>
</tr>
</tbody>
</table>

DISCUSSION AND CONCLUSIONS
Subchondral cortical and subchondral trabecular bone has thought to be the main factor defining the overall stiffness of the OA affected bone (e.g. proximal tibia). The results of this study suggest that the effect of epiphyseal trabecular bone is higher than other layers, and modest changes in this region might equate to large changes in overall stiffness. Mechanical and structural changes to subchondral cortical/trabecular bone, on the other hand, may have little effect on overall stiffness. These results suggest that epiphysial trabecular bone is a key site of interest in future analyses of OA and normal bone. These results also suggest that observed changes in epiphyseal OA subchondral bone may result in a weaker, not stiffer, subchondral bone.

REFERENCES