Design and Placement of Unicompartmental Tibial Components Based on Morphological Analysis

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Introduction: Unicompartmental arthroplasty (UKA) is an effective treatment for knees where osteoarthritis (OA) is restricted to the medial compartment. However, loosening of the tibial component is one of the main failure modes which may be associated with excessive removal of strong bone near the proximal tibia surface. Part of the reason is that the bone cut for UKA is typically made perpendicular to the long axis of the tibia, whereas the prevailing coronal plane slope of the medial plateau is usually 2-4 degrees and may be more in arthritic cases. In addition, the medial tibial surface together with the meniscus provides anterior-posterior and medial-lateral stability which should ideally be reproduced in an implant design. In this study, we analyzed the morphology of the proximal tibia in normal and arthritic knees to determine the ideal configuration for the bone resection for medial UKA implant design. Our hypothesis was that the coronal medial plateau slopes would be similar between arthritic cases suitable for UKA and normal tibias. This would imply that the bone cuts should have both sagittal and coronal slopes and that the bearing surfaces should be designed to compensate.

Methods: MRI scans of 20 normal male patients and 12 early OA male patients with Kellgren-Lawrence (KL) grade 1 - 2 were obtained with IRB approval. Additionally, 13 (de-identified) CT scans of male patients with moderate OA (estimated KL 2 - 3) from a series of UKA patients were used in this analysis. 3D-Doctor (Able Software Corp., Lexington, MA) was used to generate 3D models from MRI scans and Mimics 16.0 (Materialise, Leuven, Belgium) was used for 3D models from CT scans. In order to compare the morphological differences between normal, early OA and moderate OA cases, average models of the three groups were generated using Geomagic Design (3D Systems, Rock Hill, SC). The software used a least squares algorithm on multiple surface points to generate average points which were then used to create the surface of the average model. Next, the OA models were aligned to the normal tibia model by selecting all surfaces, but omitting the medial condyle region to a depth of 10 mm. We analyzed the medial condyle of the generated arthritic models in two ways. First, we used Geomagic software to generate deviation plots where the normal model was used as the reference, which would show any change in geometry including an increase in coronal or sagittal medial slope. Second, we measured the slopes of the medial condyle in both planes. For each of the three average models, the load bearing surface of the medial condyle was selected and a best-fit plane for the condyle was calculated by Geomagic software (Figure 1). These planes would represent the ideal bone resection plane for uniform bone removal about the central bearing area. The best-fitted planes were then projected onto the sagittal and coronal planes of the normal average
creating vectors. Using the vectors generated by the normal model as a reference, in both the coronal and sagittal planes, the angle between the normal model vectors and the arthritic model vectors were measured. This process would quantify any increase in angles produced by bone compression in the arthritic cases.

Results: Superimposing the 3 average models showed very similar morphologic features and only small differences (typically < 2 mm) between any corresponding surfaces of the models. The deviation analyses on the medial sides (Figure 2) showed that there were only small differences in bone morphology between the normal and arthritic models. For the early OA, there was approximately 1 mm lower medial surface but no increase in slope in either plane. For the moderate OA model, the deviations increased from the center to the medial side, implying an increased coronal slope.

For the projected plane analyses, the measured differences in medial slope angles between normal and arthritic cases were small (Table1). In the sagittal plane, there was minimal change in medial condyle slope angle between the early and moderate OA models, and the normal model. In the coronal plane, the medial condyle slope angle of the early OA model did not vary from the normal model, but for the moderate OA model, there was a 2.1 degree increase.

Discussion: Bone models without cartilage were used for this analysis because UKA implants are seated relative to bone, and cartilage loss varies considerably between different OA cases. The similarity between all 3 models indicated the validity of averaging bones in this way from a data base of limited size. The comparison between the medial plateaus of the early to moderate cases indicated that bone collapse occurred at a later stage than cartilage loss, and even then, within the cases we studied, the bone depression was only approximately 2 degrees. The mean planes through the medial condyles represented an ideal plane of bone resection, but at an appropriate depth below the surface consistent with component thickness and restoring the original level of cartilage. If UKA components are to provide stability, there should be some dishing of the bearing surfaces in both sagittal and coronal planes. A possible design strategy is to place this point at an average normal location, when the component is sloped at the average values for arthritic cases. Maximum deviations from the mean slopes between individual cases, approximately +/- 3 degrees, would produce only approximately 3 mm shifts in the lowest point relative to the mean value, which is clinically acceptable.

Significance: Averaging bone shapes provided a template for the design of unicompartmental tibial components, together with a proposed scheme for bone resection which minimized resection thickness. This scheme should increase the strength of bone support, important to fixation, and allow for the design of correctly positioned bearing surface dishing for stability.

![Figure 1. Average bone models of normal, early OA, and moderate OA. The normal bone shows a best-fit plane on the medial condyle. Similar planes were generated for the arthritic cases.](image)
Figure 2. The deviation maps on the medial condyles compare early and moderate OA models to the reference normal.

<table>
<thead>
<tr>
<th>Angle (degrees)</th>
<th>Coronal</th>
<th>Sagittal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early OA</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Moderate OA</td>
<td>2.1</td>
<td>0.1</td>
</tr>
</tbody>
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Table 1. Measured angles between vectors representing the medial condyle slope of normal and arthritic models in coronal and sagittal planes.