Optimal Positioning of TKA Tibia Stem Extensions in Caucasian and Asian Subjects

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Introduction: Various designs of contemporary tibia trays used in Total Knee Arthroplasty (TKA) feature keels that allow the use of modular stem extensions to enhance bone fixation in case of poor bone stock, severe bone loss, highly constrained TKA designs or revision TKA[1]. In these cases, the stem is centered in the intramedullary canal, and the position of the stem with respect to the tibial tray becomes important for proper tray placement with optimal rotational alignment, medial- and posterior slope, coverage and minimal overhang. Studies on Caucasian subjects have shown that the diaphyseal axis is generally medialized with respect the center of the tibial plateau [1,2], suggesting a medialized attachment of tibial stem extensions, whereas morphological studies on Asian subjects suggested that the intramedullary canal is lateralized with respect to the center of the tibia plateau and that tibia trays with long and/or offset tibial keels suitable for the Caucasian population may therefore not fit optimally in Asian subjects[3,4]. However, most of these analyses were based purely on the morphology of the intramedullary canal (=Canal Axis) without taking into account the fixation and axis of the stem (=Stem Fit Axis). The aim of this investigation was therefore to determine the optimal location for a stem extension in both, Caucasian and Asian subjects considering relevant design constraints of TKA such as a fixed tibial tray to stem alignment.

Methods: A total of 591 right digital reconstructed tibia models from CT scans of 192 Caucasian and 399 Asian subjects without signs of severe OA or bone deformation were virtually resected following a common surgical technique assuming a posterior slope of 5 degrees and 0 degrees medial slope at 8mm distal to the low point of the lateral condyle. For each tibia resection contour, a common coordinate system was defined at the centroid of the resection contour, with the anterior-posterior axis defined as the projected line from the medial third of the tubercle to the PCL attachment site. From all tibia bone models, the average shape of the resection contour was calculated using Principal Component Analysis. The intersection point between the resection plane and the intramedullary Canal Axis and Stem Fit Axis (Figure 1) was calculated in the resection contour coordinate system. The average location of the Canal Axis and Stem Fit Axis as well as the area covering 90% of all intersections points (i.e. multidirectional upper and lower 5th percentile) were calculated: The intramedullary Canal Axis was defined by fitting a least square linear regression line through the centers of best-fit circles through eleven evenly spaced cross-sections of the intramedullary canal in the mid-third of the tibia. In contrast to the Canal Axis, the Stem Fit Axis takes into account that for an optimal placement of the stem extension, the stem axis should be parallel to the mechanical axis in the frontal plane (varus/valgus alignment). To achieve the desired posterior slope, the stem axis should be angled with respect to the resection plane at the design specific tray-to-stem angle (for this study 5°). Furthermore, it was assumed that the stem is fixed at the distal tip centrally in the intramedullary canal and has a length of 40% of the tibia length. The Stem Fit Axis was defined by fitting a least-square-distance line parallel to the stem axis through the centers of the best-fit circles through eleven evenly spaced cross-sections of the intramedullary canal at a distance of 30% to 40% of the tibia length from the resection.
Results: The average Canal Axis and the Stem Fit Axis were both located anterior and medial to the resection centroid (Figure 2). The intermedullary Canal Axis was located in average 2.7mm (SD 2.0) more medial (paired t-test, p<0.001) and 0.9mm more posterior (paired t-test, p<0.001) than the Stem Fit Axis and showed considerably more variation indicated by the larger 90% coverage contour (dotted line) and outliers. The location of the Canal and Stem Fit Axis was significantly more medial and posterior in Caucasian than Asian subjects (see Figure 3) (Student’s t-test, p≤0.03 for all comparison). The difference between the ethnicities for the stem fit axis was smaller (1.4mm) compared to the Canal axis (3.4mm) and a large overlap between the two populations was observed.
Figure 2: Average and individual location and 90% coverage contour of the *Canal Axis* (A) and *Stem Fit Axis* (B) within the average Resection Contour.
Discussion: Since the definition of the Canal Axis is independent of the tibia resection plane, using this axis or derivatives of it as the reference axis for the stem placement might result in an undesired varus / valgus alignment of the tibia tray. Therefore, a new definition of the Stem Fit Axis is proposed to define the optimal location for a stem extension with respect to the resection contour. Though this axis leads to a more relevant stem location for TKA, at the same time it is dependent on specific TKA design characteristics (i.e. posterior slope, tray-to-stem angle). In contrast to previous findings [3,4], the average Stem Fit Axis in Asian subjects was not lateralized but rather centralized with respect to the resection contour centroid. This difference may be due to different definitions of the canal axis and coordinate systems. Although the average Stem Fit Axis was located significantly more medial in Caucasian compared to Asian subjects, the difference and hence its relevance for TKA design was small and a large overlap between the two populations can be observed suggesting that TKA designs with moderate medialization of the stem extension will fit both populations equally well.

Significance: The new proposed Stem Fit axis definition that accounts for the technical constraints in TKA designs leads to less variability for optimal positioning of tibial stem extensions and shows that TKA designs that consider these findings would fit Caucasian and Asian subjects equally well.

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