Appendix: Isolating the anteromedial aspect of the medial tibial eminence

Isolating the anteromedial aspect of the medial tibial eminence to measure its volume required four main steps: (1) reconstructing three-dimensional, volumetric representations of each tibia from their computed tomography (CT) scan; (2) assigning a tibial coordinate system; (3) identifying a set of points along the ridge of the medial tibial eminence; and (4) defining boundaries for the anterior, lateral, and distal aspects of the medial tibial eminence. Steps two to four were completed via custom code generated using MATLAB (v2016b, Natick, MA).

First, we reconstructed three-dimensional, virtual models of each tibial bone from a CT scan of each specimen[1]. The scans were imported into the medical image processing software, Mimics (Materialise Inc., Leuven, Belgium), segmented using grey value thresholding, and converted into three-dimensional models in stereolithography format. These data were subsequently imported into Geomagic software (3D Systems Inc., Rock Hill, SC), smoothed, and remeshed to a uniform point distribution (40% smoothing, 0.5 mm target edge length). Finally, each tibial geometry was truncated to include its proximal 15 cm; the minimum length of tibia that was available across all of the knees tested in our robotic experiment. Second, we defined the tibial coordinate system using the method developed by Kai, et al[2] and others[1], which utilized principal component analysis to identify the anatomical directions.

In step three, we determined a set of points along the ridge of the medial tibial eminence, which we called the ridge points (Fig. 1A). To identify the ridge points, first, a point located centrally on the medial plateau was identified and served as a reference point for our algorithm. This point was located at the peak of the medial tibial eminence in the AP direction, 25% of the length of the major axis of the most contoured ellipse in the ML direction[2], and the origin of the tibial coordinate system in the proximal-distal (PD) direction. The value of 25% was chosen because it yielded a point located at the approximate center of the medial plateau. A sagittal plane containing this point was then created and the subset of points from the tibial point cloud residing within 0.2 mm of either side of this plane were determined. Next, the point with the largest value in the proximal direction (i.e., in the +Z direction) of the tibial coordinate system was identified. This process was repeated in 2° increments of rotation about the PD-directed axis until 90° of rotation was achieved leaving the plane oriented coronally and intersecting the peak of the medial tibial eminence. Altogether, this third step yielded a set of points that extended from the peak of the medial tibial eminence, followed a path down the anterior portion of the medial tibial eminence, and then curved medially along the anterior aspect of the tibial plateau (Fig. 1).

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We defined the lateral boundary to parallel the AP direction of the medial tibial eminence (Fig. 1B). To specify this boundary, we first divided the peak path into two subsets of points: an anterior half and a posterior half. The posterior subset of points paralleled the AP direction of the medial tibial eminence. In contrast, the anterior subset curved medially around the anterior portion of the medial tibial plateau and diverged from the anterior direction of the medial tibial eminence. Thus, the posterior subset of points better identified the AP direction of the lateral boundary than the anterior subset (Fig. 1B). To identify this AP direction, we projected the coordinates of the posterior subset onto the transverse (XY) plane and fit a line (via least squares approximation) to them. This line was then extended proximally and distally parallel to the Z-axis of the tibial coordinate system to define the lateral boundary of the medial tibial eminence.

Finally, we defined the distal boundary of the medial tibial eminence to be parallel to the transverse (XY) plane of the tibial coordinate system. The distal location of this plane was defined using a specific point from the set of ridge points (from step 3 above) as follows (Fig. 1C). First, we measured the medial-lateral distance (i.e., along the X-axis of the tibial coordinate system) between the peak of the medial tibial eminence and the most medial point of the tibia. Next, a plane parallel to the lateral boundary was offset medially by 10% of this distance. The points from the peak path that were medial to this plane were eliminated; the distal boundary intersected the most distal of the remaining points (Fig. 1C). The posterior, lateral, and distal boundaries were used to isolate the anteromedial portion of the medial tibial eminence, and the volume was subsequently calculated.

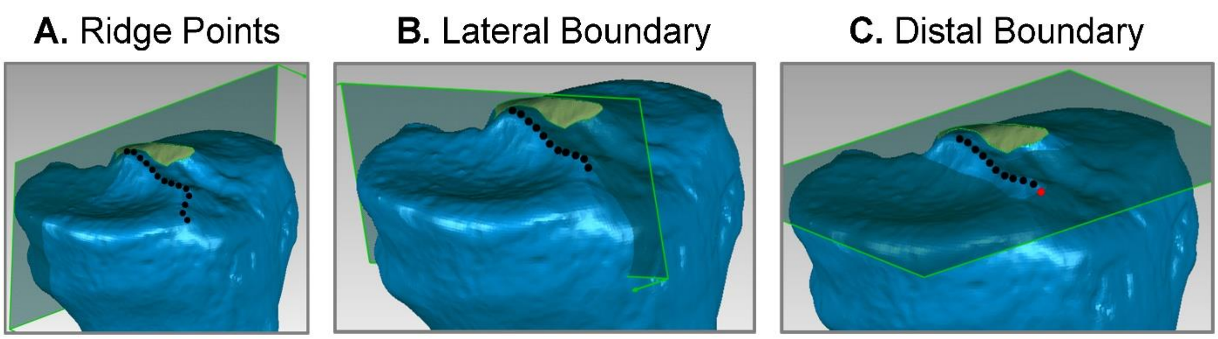

Figure 1: Major steps required to isolate the anteromedial portion of the medial tibial eminence from 3D reconstructions of the tibia. A) A set of points along the ridge (ridge points) were identified and the posterior boundary of the anterior portion of the medial tibial eminence was defined using the most proximal, or peak point from this set. B) The lateral boundary of the medial tibial eminence was established using a subset of the ridge points. C) The distal boundary of the tibial eminence was also identified based on a specific point within the set ridge points (in red).

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