QUANTIFYING HUMAN KNEE ANTHROPOMETRIC DIFFERENCES BETWEEN ETHNIC GROUPS AND GENDER USING SHAPE ANALYSIS TECHNIQUES

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INTRODUCTION

Optimal restoration of normal knee anatomy is one of the primary objectives for successful total knee arthroplasty (TKA). Total knee replacements have their design basis of some form of "averaged" knee anthropometry, although the population group and sample size over which the averaged anatomic data is obtained varies between total knee replacement manufacturers. Orthopaedic surgeons have reported either insufficient implant bone coverage or implant overhang in designs across the industry as a result of sub-optimum implant fit [1].

Although there is evidence to suggest that there are gender differences in the anteroposterior to mediolateral dimension aspect ratios of the femoral condyle [2], the actual anatomical differences between gender may be more complex than this simple relationship. This is also true for ethnic group variations, as concluded in a study published for a generally smaller-sized, south Asian Indian population [3]. More rigorous knee anthropometry data mining is necessary to more precisely assess global knee morphological variations.

Recent advances in quantitative computed tomography (CT) image processing have enabled researchers in this study to develop a comprehensive "virtual bone database" (VBD). Using the VBD, in conjunction with shape analysis techniques, a systematic methodology was established to consistently measure distal femur and proximal tibia anatomic dimensions between Asian and Caucasian population groups and then between males and females within those ethnic groups.

Statistical comparisons between these groups were then made to establish their statistical significance and what role these differences should play in next generation knee prosthesis designs.

METHODS

Landmark dimension selection: Figure 1 presents the anatomical landmarks dimensions which were measured in this study.

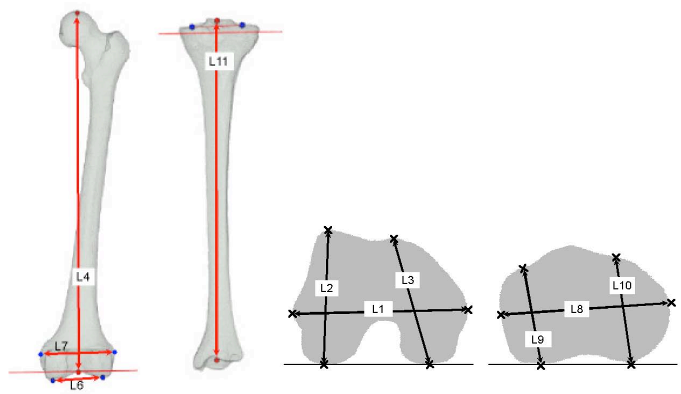

Figure 1: Anatomic landmark measurement locations

Landmarks L1-L3 apply to the distal femur and are measured from a virtual cutting plane which is normal to the mechanical axis, 8mm above the medial point between the femoral condyles.

Landmark L4 correponds to the femoral length, while Landmark L5 corresponds to the overall anterior posterior dimension of the distal femur as measured in the sagittal view.

Landmark 6 corresponds to the M/L width of the most distal points of the femoral condyles when viewed from the frontal plane, while Landmark 7 corresponds to the transepicondylar line length.

Landmarks L8-L10 apply to the proximal tibia and are measured from a virtual cutting plane which is normal to the mechanical axis, 6mm below the sulcus of the tibial condyles, while Landmark 11 corresponds to the tibial length.

Population selection: A total of 65 right femura and 57 right tibiae, processed from CT scans of slice thicknesses ranging from 0.7 to 1.5mm, were randomly selected from the VBD. These patients range in age from 19 to 85 years.

The dataset was further divided by gender and by ethnic group (i.e.; East Asians and Caucasians), as presented in Tables 1-4.

Dimension processing methodology: CT scan image segmentation was performed in a semi-automatic fashion to extract the outer cortical surface profiles of the femur and tibia.

After image segmentation, reference bone images were selected for the femur and tibia and a combined affine and non-rigid image registration approach [4] is employed to establish corresponding anatomical points across the images. Given a point x in the reference image, we target a corresponding point x′ such that $x' = A^{-1}(\phi'^{-1}(x))$, where A and ϕ are the affine and non-rigid transformations needed to morph every bone image onto the reference bone image. The affine transformation allows for large scale deformations, whereas the non-rigid transformation captures the local shape variations.

Anatomic landmarks are selected interactively by mouse clicking on locations on the reference bone using a graphical user interface in which the reference bone is viewed and can be rotated in 3D space. The positions identified on the reference bone are transformed to the equivalent position on the clinical bone images, from which dimensional data is extracted and stored. The landmark selection process was later enhanced to allow for landmarks to be defined on specific cutting planes.

RESULTS

The results of the statistical evaluation (using the Mann-Whitney U-Test) are presented in Tables 1-4.

DISCUSSION and CONCLUSIONS

A statistically significant difference in the distal femur and proximal tibia dimensions was found between males and females, but not between Asian and Caucasian groups.

The automated algorithm for anatomical landmark dimensioning facilitates the ability to measure and analyze large datasets quickly and consistently, circumventing slower, error prone manual measurement techniques previously implemented. Ongoing work includes increasing the sample size, extending anatomical landmarks dimensions to other measurements including radii (e.g.; femoral head diameters and femoral bow) and angles (e.g.; femoral neck angle). The processing will also be enhanced to include automatic first order statistical analysis for the output data sets.

Table 1: Femoral Dimensions by Ethnic Group, mm (n=65)

Landmark ID	Asian (n=41) Mean (σ)	Caucasian (n=24) Mean (σ)	P value
L1	70.5 (5.8)	73.6 (6.2)	0.057
L2	50.7 (3.9)	52.7 (3.6)	0.073
L3	51.1 (3.9)	52.8 (3.6)	0.092
L4 (length)	423.7 (30.5)	445.2 (2.4)	0.005
L5	63.0 (4.9)	65.3 (4.5)	0.097
L6	55.1 (4.5)	57.6 (4.8)	0.055
L7	81.5 (6.7)	85.2 (7.1)	0.054

Table 2: Femoral Dimensions by Gender, mm (n=65)

Landmark ID	Males (n=33) Mean (σ)	Females (n=32) Mean (σ)	P value
L1	76.0 (4.1)	67.2 (4.3)	< 0.001
L2	54.1 (3.0)	48.8 (2.8)	< 0.001
L3	54.2 (2.9)	49.2 (2.9)	< 0.001
L4 (length)	450.0 (22.0)	412.6 (24.9)	< 0.001
L5	67.0 (3.7)	60.5 (3.5)	< 0.001
L6	59.4 (3.2)	52.4 (3.4)	< 0.001
L7	87.9 (4.7)	77.6 (5.0)	< 0.001

Table 3: Tibial Dimensions by Ethnic Group, mm (n=57)

Landmark ID	Asian (n=36) Mean (σ)	Caucasian (n=21) Mean (σ)	P value
L8	80.7 (6.6)	78.9 (5.4)	0.313
L9	44.7 (3.3)	44.8 (2.9)	0.585
L10	46.2 (3.5)	46.4 (2.9)	0.540
L11 (length)	340.1 (23.3)	357.9 (14.0)	0.003

Table 4: Tibial Dimensions by Gender, mm (n=57)

Landmark ID	Males (n=25) Mean (σ)	Females (n=32) Mean (σ)	P value
L8	84.2 (5.3)	76.8 (4.8)	< 0.001
L9	47.2 (2.3)	42.9 (2.4)	< 0.001
L10	48.7 (2.3)	44.4 (2.6)	< 0.001
L11 (length)	357.9 (17.8)	338.9 (2.1)	< 0.001

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