CAN A SINGLE SCALE FACTOR BE USED TO SCALE FEMUR BONE MODELS?

[1,2] Weidong Luo, [2]Zohara Cohen and [2, 3]Frances Sheehan
[1]Physics Department, Catholic University of America; [2]Physical Disabilities Branch, National Institutes of Health;
[3]Department of Physical Therapy and Rehabilitation Science, University of Maryland School of Medicine
email: wluo@cc.nih.gov, web: http://pdb.cc.nih.gov/

INTRODUCTION

A generic bone template must be scaled to quantify the shape differences between it and a particular bone. Computational joint models rely on the scaling of a generic model to approximate the bone geometry of an individual subject. Previous modeling studies have used both single [1-3] and multiple scale factors [4] to approximate individual femurs from templates. The objective of this study was to determine whether a single scale factor is sufficient. We examined normal subjects to determine whether consistent relationships exist between designated femur lengths. We hypothesized that multiple scale factors would be necessary: three factors for the superior-inferior direction (corresponding to proximal, mid-shaft, and distal sections of the femur) and one scale factor each for the anterior-posterior and medial-lateral directions.

METHODS

Landmark coordinates for 52 skeletal femur specimens were obtained from an existing database [3]. Landmark coordinates for ten volunteers were obtained from geometric models generated using Geomagic Studio (Research Triangle Park, NC) based on data segmented from T1-weighted MRI scans. Volunteer and skeletal specimens were all skeletally mature and free from known orthopaedic abnormalities. Relevant lengths were measured as the distances between the following pairs of landmark points: the most lateral points on the greater trochanter and on the femoral epicondyle (LE) (referred to as "palpable length" due to the accessibility of the landmarks); the top of femoral head and the inferior base of lesser trochanter (LT) ("proximal length"); the superior corner of adductor tubercle (AT) and the most inferior point on the femur ("distal length"); LT and AT ("shaft length"); the most medial point on the femoral epicondyle and LE ("width"); and the origin of the VMO fibers (near the anterior-medial corner of the patellar groove) and a line connecting the most posterior points on the medial and lateral distal condyles ("depth"). Kolmogorov-Smirnov (K-S) normality tests were performed to ensure normally distributed measurements and that further statistical testing was appropriate. Correlations were sought between the palpable length, a measurement that could potentially serve as the basis for a uniform scale factor, and each of the other lengths. For each correlation, the lower and upper bounds on the 95% confidence interval were found. Measurements were normalized by their respective mean values and linear regression analysis (with y intercept=0) performed to determine the rate of change of each length with change in palpable length. The regression coefficients for these normalized data were compared.

RESULTS AND DISCUSSION

The palpable length for the 62 test subjects was 382 ±25 mm. The standard deviations for the five test measurements, when normalized by their means, ranged from 6% to 13% (Table 1, row 1). The distribution of these data was found to be normal in all cases; the Lilliefors significance level was well above 0.05 for the K-S tests (row 2). Significant (p-values <0.0001) correlation values (R) relating each of the five dependent measures to the palpable length ranged from 0.50 for (depth) to 0.96 (shaft length) (row 3). The 95% confidence intervals were narrow and the lower bounds found for R were never lower than 0.29 (row 4) and the upper bounds were as high as 0.98. The strong correlations for the three length measurements indicate that individual femoral sections change size proportionally to changes in femoral length. The width and depth correlations indicate that the changes in the two orthogonal dimensions are also proportional to the superior-inferior femoral dimension. The linear regression model proved valid as all models demonstrated significance (t-value >>2 and significance << .01). The most important finding was that the regression coefficients for the normalized data were all the same (row 5), indicating that, not only do all five parameters vary with the palpable length, they vary at the same rate. Thus, we have shown that when scaling a model femur to match an individual femur, a single scale factor is sufficient to match the three sections and three dimensions of the bone.

REFERENCES

1. Arnold AS, et al. *Comput Aided Surg* **5(2)**, 108-19, 2000.
2. Jenkins, SE, et al. *Gait Posture* **18(1)**, 13-22, 2003.
3. Keppel, TM, et al. *J Biomech* **31**, 77-80, 1998.
4. Arnold AS, et al. *Ann Biomed Eng* **29(3)**, 263-74, 2001.

ACKNOWLEDGEMENTS

We are grateful to the PDB investigators at the NIH who shared with us the skeletal specimen data.

Table 1: Statistical measurements

	proximal length	shaft length	distal length	width	depth
1 **Mean ± Standard Deviation (mm)**	98.4±9.3	328.2±23.0	49.1±5.0	87.3±9.1	77.9±10.5
2 **Lilliefors significance for K-S Test**	0.85	0.82	0.54	0.37	0.77
3 **Pearson's R Value**	0.56	0.96	0.56	0.54	0.50
4 **Lower Bound for 95% CI for R**	0.36	0.94	0.36	0.34	0.29
5 **Normalized regression coefficients**	1.00±0.01	1.00±0.01	1.00±0.01	1.00±0.01	1.00±0.01
6 **Standard error of estimation (mm)**	7.8	6.4	4.1	7.7	9.1