EFFECTS OF ADDUCTION MOMENT, BODY WEIGHT, AND BONE SIZE ON TRABECULAR BONE STRESS

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INTRODUCTION:

Various factors, including adduction moment (AM), body weight (BW) and bone size (BS), may affect the amount of stress throughout the proximal tibial trabecular bone. Increased forces onto the tibial plateau as a result of a high AM or BW are believed to be associated with osteoarthritis in adults [1] or angular deformities in children [2]. To offset these high forces, it has been suggested that bones may be greater in size in those who are overweight, therefore reducing stress [3]. A finite element (FE) model and a full factorial design approach was used to determine the relative effects of AM, BW and BS on trabecular bone stress throughout the proximal tibia.

METHODS:

Finite Element Model

A three-dimensional FE model of the proximal tibia was created from magnetic resonance (MR) images of a 30-year old male (wt: 54 kg, ht: 1.7 m) (Figure 1). Sagittal slices were collected using a gradient recalled echo (GRE) MR sequence (slice thickness: 1.5mm, in-plane resolution: 0.27) to define geometry of the bone and articular cartilage. Isotropic linear elastic material properties were used [4,5]. Tibio-menisco-femoral joint contact pressure was applied to the tibial plateau over areas determined from the MR image. This method of applying pressure was compared to a validated model of tibio-menisco-femoral joint contact and resulted in a similar stress distribution in the trabecular bone while requiring a significantly shortened analysis time [6]. The model was analyzed using FE software ABAQUS standard 6.3 (HKS, Inc.).

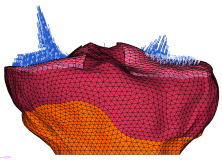

Figure 1: FE Model

Full Factorial Design Approach

A full factorial design was used to study the effects of AM, BW and BS on trabecular bone stress, with three levels for each factor. The levels used were the average and average ± 2 times the standard deviation, as estimated from ranges found in the literature. In a gait analysis study of 158 subjects, peak knee AM was found to be 3.0 ± 0.7 (%BW*Height) [7]. This AM was used to estimate the ratio between peak forces on the medial and lateral plateaus [8]. BS levels were determined from Ding et al, where MR images were obtained from 372 normal and overweight subjects and tibial bone area was measured. The FE model was then "morphed" to represent the larger or smaller bone size. Center for Disease Control (CDC) percentiles for BW were used based on the 3rd, 50th, and 97th percentiles for the same height, age and gender as the subject from whom we acquired MR images

Principal stress values were analyzed separately for medial and lateral compartments of the tibia. Results were analyzed for elements attached to the growth plate scar and below the articular cartilage, and the average compressive principal stress was used to assess effects.

RESULTS:

According to the statistical analysis, in the medial growth plate region only 4% of the variance (sum of squares) in trabecular bone stress was contributed by BS, whereas AM and BW contributed 23% and 70% respectively. As expected, stress throughout the medial trabecular bone was greater as BW and AM increased, and the same was seen when BS decreased (Figure 2).

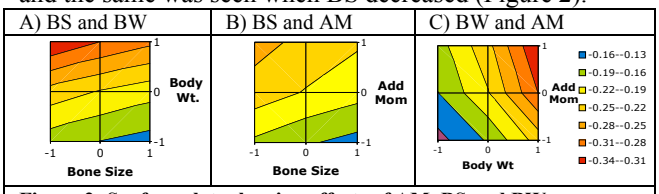

Figure 2: Surface plots showing effects of AM, BS and BW on trabecular bone stress (MPa) in the elements surrounding the medial growth plate. The three levels for each case are shown: small (-1), average (0) and large (+1). The case not included was set to the average (0).

Contour plots of the two extreme cases of our analysis show significant variations in principal stress distribution from a mid frontal slice of the proximal tibia (Figure 3).

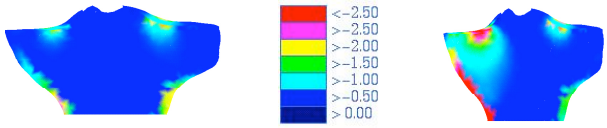

Figure 3: Contour plots for the lowest and highest stress cases considered. A) Lowest stress: Large BS(+1), small AM and BW(-1). B) Highest stress: Small BS(-1), high AM(+1) and BW (+1).

DISCUSSION:

Our results show that loading conditions have the largest effect on bone stress in the proximal tibia. Since AM and BW are factors that may be adjusted with appropriate training, shoe inserts, or weight loss, this knowledge may be beneficial to clinicians treating patients with knee pain. Our results demonstrate the importance of accurate loading conditions, and suggest that they may be more important than subject specific geometry. Our current study used BS levels not including subjects who were underweight. Thus we cannot be certain how much effect BS might have. Future studies should identify the full range of BS, and also consider variations in bone material properties, as well as other differences in geometry and curvature of the tibial plateau.

REFERENCES:

[1] Gelber, A.C. et al, 1999, *Am J Med*, 107:542-548. [2] Henderson, R.C., 1992, *J Ped*, 482-486. [3] Ding, C. et al, 2005, *Obes Res*, 13:350-361. [4] Ding, M. et al, 1997, *J Bone Joint Surg*, 79B:995-1002. [5] Yao, J. et al, 2006, *J Biomech Eng*, 128:399-408. [6] Yao, J. et al, 2007 ORS poster #767. [7] Moisio, K.C. et al, 2003, *J Biomech*, 36:599-603. [8] Hurwitz, D.E. et al, 1998, *J Biomech*, 31:423-430.

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