REGION-SPECIFIC STRAIN ENERGY IN THE PROXIMAL FEMUR DURING LOAD-BASED ACTIVITIES IN ELDERLY WOMEN

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INTRODUCTION
Exercise may slow bone loss and maintain bone’s structural integrity [1-2]. However, the stresses and strains responsible for focal adaptive changes in bone structure in response to joint and muscle forces during exercise are not quantified. To achieve this, and so design programs to maintain bone health, we compared the strain energy density in four regions of the proximal femur during jumping, stair ascent, and stair descent.

METHODS
Pilot data from five postmenopausal women (age range = 60-74) with no history of fractures or drug therapy influencing the skeleton was obtained. The ethics committees of The University of Melbourne and the Austin Health approved the study.

Subjects were asked to jump in place, and ascend and descend a series of stairs without the use of handrails. Three dimensional joint motion, ground reaction forces and muscle EMG activity were recorded simultaneously for five trials of each task. Computed tomography (CT) data of the femur of the dominant leg for each subject were also acquired (Aquilon CT, Toshiba) (Fig. 1). Scans were taken using 120kV, 200mA, and 0.5mm sized voxels.

A generic musculoskeletal model was scaled to each subject’s anthropometry using OpenSim [3]. The joint angles and torques were calculated using inverse kinematic and dynamic analyses, respectively. Muscle forces were calculated using a static optimization algorithm in which the sum of the squares of the muscle activation was minimized. The hip joint reaction force was found by solving a static equilibrium problem for the femur.

Finite element models of the femur of the dominant leg of each subject were created (Fig. 1). Each femur was segmented from the CT scans (Amira v5.3, VSG, USA) and converted into solid models (Geomagic v10, Geomagic, USA). A finite element package (Abaqus v6.11, Simulia, France) was used to discretize the bone into quadratic tetrahedral elements and each element was assigned an isotropic Young’s modulus based on the relationships between Hounsfield units and Young’s modulus (Bonemat, Supercomputing Solutions, Italy) [4]. The muscle forces and hip joint reaction force from the musculoskeletal model were applied.

Figure 1: Women over 60 years of age (A) were asked to jump in place, ascend stairs, and descend stairs. Musculoskeletal models (B) were used to calculate muscle and hip joint loads at the femur. CT data from each subject (C) was used to create models of the femur with a heterogeneous distribution of bone strength values. A finite-element model (D) of the femur was used to calculate the stain energy (E) in the proximal femur.
as nodal boundary conditions for each time increment of the activity, and the distal end of the femur was kinematically constrained. A linear implicit analysis was used to calculate the strain energy (a specific indicator of bone remodeling) in the proximal femur.

Strain energy density comparisons: Four regions of the proximal femur were compared: (1) proximal neck, (2) distal neck, (3) greater trochanter, and (4) lesser trochanter (Fig. 2, inset images). The strain energy density within each region (strain energy/volume) was calculated for all activities. A paired t-test ($\alpha = 0.05$) was used to compare the total strain energy density (the area under each curve in Fig. 2) during jumping, stair ascent, and stair descent.

RESULTS AND DISCUSSION
During jumping, there was no difference in the total strain energy density by region (Fig 2). For stair ascent, the total strain energy density within the proximal femoral neck was higher than that in the distal femoral neck ($p = 0.03$) (Fig. 2, compare gray lines in A and B). The strain energy density during stair descent was also higher proximally than distally ($p = 0.03$). Within each region, the total strain energy density was not different regardless of activity.

Two peaks in strain energy were observed during jumping: one for the crouch phase during which the subject prepares to jump and the second for the impact phase of jumping. Interestingly, our results suggest that the act of crouching, which requires hip and knee flexion, generates as much strain energy as impact loading. Understanding the specific contribution of the hip and knee flexors to the strain energy response during jumping may help in the development of non-impact based exercise protocols that are safer for the older populations to which they are targeted.

A limitation of this study is the qualitative verification of muscle force calculations by comparison of their magnitudes with EMG data. Also, the material properties of the finite-element model have been validated against cortical surface strain alone. Finally, the statistical power of this study is limited by the sample size. However, a differentiation of the regional response of bone to loads was possible.

CONCLUSIONS
The effect of stair climbing and descending was higher in the proximal than distal femoral neck. Femoral fractures are more common in the proximal region, and so safely targeting this region with exercises may be a feasible approach to preserving bone structure and reducing age related increases in bone fragility.

REFERENCES

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