THE EFFECTS OF PHYSICAL ACTIVITY ON PREDICTED BONE DENSITY AND MICRODAMAGE ACCRETION OF THE FEMUR

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INTRODUCTION

An individual's physical activity level is thought to have a major influence on the density of load-bearing bones. For instance, significantly denser bone has been found in athletes compared to exercising and non-exercising controls (Nilsson and Westlin, 1971). Also, disuse studies have shown a severe amount of bone loss following bed rest or immobilization (Minaire et al., 1974; Whedon, 1984). Here, we used a bone remodeling simulation to study the effects of physical activity on bone density and damage accretion of the femur.

METHODS

A modified version of an internal bone remodeling simulation was used for this study (Fig 1, Hazelwood et al., 1997). In this model, bone density changes were determined by the amount of bone removed or added by active resorbing or refilling basic multicellular units (BMUs), respectively. Remodeling by BMUs was activated to remove damage and to eliminate bone in disuse. The mechanical stimulus, Φ, for remodeling was assumed to be proportional to the product of the strain range (s) raised to a power and the loading rate (R_L) from n different activities:

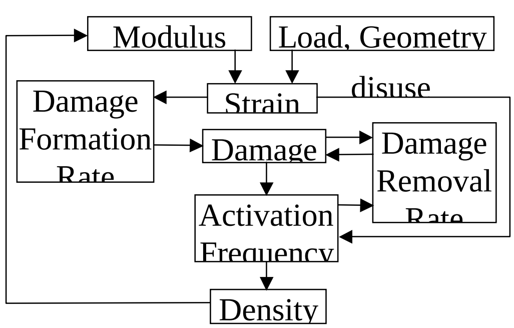

Figure 1. Bone remodeling algorithm.

$$\Phi = \sum_{i=1}^{n} s_i^q R_{Li}$$

The strain quantity, s, was assumed to be the principal strain with the maximum magnitude and the exponent, q, was set to 4. Disuse was defined as values of Φ below a set-point mechanical stimulus. Damage in bone was assumed to accrete at a rate proportional to the stimulus Φ. The damage removal rate was assumed to be proportional to the damage in the region, the BMU activation frequency, and the area resorbed by each BMU.

A 2-D finite element model (linearly elastic, isotropic), consisting of 4216 4-node quadrilateral elements, was created from a representative femur. A bony side plate was added to account for the out-of-plane cortical bone. Three load cases (single leg stance, abduction, and adduction), each consisting of joint reaction and abductor muscle forces, simulated the daily loading history for normal activity [equivalent to a femoral loading rate of 6000 cycles per day (cpd)]. Modulus-density relationships were determined from empirical data for both cortical and trabecular bone. The model's elements were initially assigned homogeneous material properties, and the modulus of each element was allowed to evolve over time.

A femur model for normal activity of an 800N person was run using ABAQUS 5.8 until the remodeling parameters achieved steady state. Using these results as the initial condition, remodeling was examined for an additional 1200 days for five different activity levels: (1) continued normal activity for the added period (baseline), (2) a 20% decrease in loading and activity, (3) a 20% increase in loading and activity, (4) a training schedule for runners varying between 25 and 40 miles per week (0 to 12 miles per day), and (5) daily running at 40 miles per week (an additional 3643cpd of loading on the femur).

Table 1. Predicted Femoral Density Results
[% increase (+) or decrease (-) of baseline]

	trochanter	prox. cortex	neck	head
activity				
20% decrease	-20.9	-22.2	-16.5	-18.6
20% increase	6.5	1.3	3.3	6.1
training sched.	3.0	-0.9	1.1	2.1
daily running	5.4	-3.1	0.7	5.4

RESULTS AND DISCUSSION

Inducing disuse by decreasing loading and activity by 20% had a substantial affect on femoral density compared to a 20% increase in loading and activity (Table 1). Bone loss in disuse was nearly equal in both cortical and trabecular bone regions, with most of the decrease in the cortical region found on the endosteal surface of the femoral shaft. When loading and activity were increased by 20%, density and damage increased slightly in the trabecular regions of the trochanter, neck, and head of the femur, with only minor increases observed in the cortical bone of the neck and proximal diaphysis.

Running according to a training schedule, with varying mileage and rest periods, produced smaller changes in the density of the femur than running performed on a daily basis, except in the neck region where density increases were approximately the same for both simulations (Table 1). Damage was 19 to 30% greater for daily running compared to the training schedule. Bone density decreases were observed in the proximal cortex for both running conditions. Modeling effects, which were not included in this simulation, may account for the net increase in bone density that has been observed in this region (Dalen and Olsson, 1974).

Although most stress fractures in athletes occur in the tibia, reports indicate that as many as 21% may occur in the femur (Johnson et al., 1994). These femoral fractures mainly appeared in the proximal cortex of the shaft and the inferior neck, locations which correspond to regions of high damage accretion in both running simulations (see Fig. 2 for daily running).

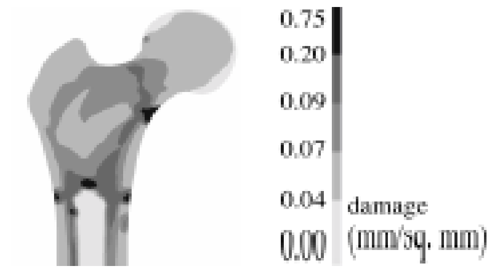

Figure 2. Increase in damage for the daily running condition at 40 miles per week compared to the baseline (normal) activity. Damage is defined as microcrack length per area bone.

SUMMARY

A simulation for internal bone remodeling was utilized to investigate the effects of physical activity on femoral bone density and damage accretion. While exercise may be useful in maintaining bone mass, disuse may lead to severe bone loss in the femur. A 20% decrease in loading and activity was observed to substantially reduce bone density in both cortical and trabecular bone. A 20% increase, on the other hand, produced only slight increases in density, primarily in the trabecular regions.

The training schedule reduced the femoral remodeling activity compared to the daily running schedule. The rest and varying mileage of the training schedule allowed the bone to more efficiently remove damage in all regions examined. Regions of high damage accretion for both running simulations correspond to observed locations of femoral stress fractures, indicating that the simulation may be useful in predicting fracture sites.

ACKNOWLEDGMENTS

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REFERENCES

Dalen et al. (1974) *Acta Orthop Scan* 45:170.
Hazelwood et al. (1997) *Proc 21st ASB*, 256.
Johnson et al. (1994) *Am J Sp Med* 22:248.
Nilsson, Westlin (1971) *Clin Orthop* 77:179.
Minaire et al. (1974) *Calcif Tiss Res* 17:57.
Whedon (1984) *Calcif Tiss Int* 36:S146.