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Response of trabecular bone to elevated loading frequencies

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ABSTRACT

Introduction: External mechanical loading stimulates bone to proliferate and mineralize. However, the exact specification of the loading parameters is unclear and inconsistent due to variations in experimental design and methodology. This study examined the response of trabecular bone to fatigue loading under various frequencies.

Materials and methods: Six bovine lumbar (L5) vertebral bodies were sectioned in the axial plane at the midheight to expose a flat surface of cancellous bone. Testing locations identified as 1–7 were subjected to 535 cycles of sinusoidal loading from –2 N to –15 N using a 1-mm diameter indentor and a materials testing machine (Bose ELF 3200, Minnetonka, Minnnesota). Site 1 was located in the center of the vertebra with the six additional sites surrounding the center. Continuous load versus deformation data were recorded at cycle 10 and at subsequent 25 cycle intervals thereafter with the deformation data averaged across the respective cycle number for all vertebral test sites. The testing and deformation extraction process was repeated for subsequent vertebral body specimens using testing frequencies of 1 Hz, 2.5 Hz, 5 Hz, 7.5 Hz, 10 Hz, and 20 Hz. The average deformation over the number of test cycles for each frequency was subjected to nonlinear exponential.

Results and Discussion: Results of the nonlinear exponential regression indicated at that at test frequencies >5Hz, a single exponential was sufficient to fit the resulting deformations data, whereas dual exponential functions were required to appropriately fit the deformation data below 5 Hz. (*F*-test) The dual exponential functions were characterized and compared with *K* (fast) (rate constant of deformation for fast phase of exponential decay), *K* (slow) (rate constant of deformation for the slow phase of exponential decay), and Y_0 (initial net deformation). The two *K* values for the dual exponential functions were compared to the *K* values for the single exponential functions using a one-way ANOVA and Tukey's posthoc test for multiple comparisons across frequencies. When comparing *K* (slow) values to the single exponential (higher frequency) *K* values only the 20-Hz test frequency was not statistically different from the low frequency *K* (slow) values. The 10-Hz and 7.5-Hz test frequency *K* values were statistically elevated when compared with the 1 Hz, 2.5 Hz, and 5 Hz *K* (slow) values ($P < 0.05$ for all comparisons). When comparing the *K* (fast) values to the single exponential (higher frequency) *K* values, there were no statistically significant differences within the high frequencies (7.5 Hz, 10 Hz, and 20 Hz) but the frequencies at or <5Hz were all statistically elevated when compared with the high frequencies. The preferred dual exponential fitting at low frequencies combined with preferred single exponential fitting at higher frequencies may be indicative of altered changes in the flow of the fluid component comprising the bone structure.

Conclusions: The results of this study indicate that elevated frequency loading can alter the bone response and lead to stiffening of the structure. Such a finding may explain the propensity toward increased incidence of spinal degeneration often associated with those individuals subjected to elevated frequency loading due to occupational exposures.