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# Stiffness response of bone to elevated frequency loading

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## ABSTRACT

*Introduction*: Wolff's Law qualitatively describes the response of bone to loading conditions. This study examines the interaction and dependence of loading frequency on the fatigue response of bone under axial load. It has been surmised that exposure to elevated frequencies may increase bone stiffness. The resulting stiffness response of bone based on work generated under sinusoidal loading over a range of frequencies was investigated. Elucidating the response characteristics of bone will help to determine the optimal loading conditions which stimulate bone growth and may be applicable to the improvement of bone fusion regimens as well as design of bioreactor systems.

*Materials and Methods*: A 10-mm trephine was used to extract the central core from 30 frozen thoracic (T9, T10, T11) porcine vertebral bodies (Animal Technologies Inc., Tyler, Texas). The resulting heights from each of the cylindrical specimens of cancellous bone were recorded and used to normalize the resulting deformation data under loading. Cylindrical specimens were milled to achieve parallel surfaces for loading in phosphate-buffered saline. Specimens were subjected to compressive sinusoidal fatigue loading from –2 N to –15 N for 535 cycles at randomly selected rates of 1 Hz, 2.5 Hz, 5 Hz, 7.5 Hz, and 10 Hz using a materials' testing machine with continuous load versus deformation data acquired at cycle number 10 and at subsequent 25 cycle intervals thereafter. Stiffness at recorded cycle intervals was computed from the elastic region of the load versus deformation curve.

At each axial count, the stiffness of the loading phase of the cycle was computed by determining the slope of the load versus deformation curve in the elastic region. A plot of the mean stiffness versus cycle number at each loading frequency tested was subjected to a nonlinear analysis (Prism 5.0, GraphPad Inc., San Diego, California). The resulting curve parameters of rate ($K$), plateau, stiffness change (span), and half-time were normalized to initial stiffness ($Y_0$) and statistically analyzed using a one-way repeated measures ANOVA test with a Tukey posthoc test.

*Results and Discussion*: The results of compression based on applied loading frequency are provided. The resonant frequency of the spine has been cited at 5 Hz. In addition to this 5 Hz resonant frequency, harmonics at 1 Hz and 10 Hz were also found to increase cycles required to achieve stability, as demonstrated by statistically increased half-life values seen at these loading rates. Among the half-life values, no statistically significant differences were found between the 1 Hz and 5 Hz, 1 Hz and 10 Hz, or 5 Hz and 10 Hz frequencies. All other comparisons were statistically significant ($P < 0.05$).

*Conclusions*: The mechanical response of bone is highly dependent on loading frequency. This study demonstrates that increased stiffness at elevated loading frequencies may lead to predisposition of pathological clinical conditions. Frequency of loading rate should be considered as stiffness changes display preferential values near 2.5 Hz, 5 Hz, and 10 Hz.