

Comparison of Structure-based Scaling and Mass-based Scaling Methods Applied to Long Bone Mid-Shaft Bending Tests

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Abstract

The objective of this study was to compare structure-based and mass-based scaling methods for scaling long bone bending tests results. Although scaling methods are widely used in predicting injury tolerances and developing impact response for biofidelity assessment, these scaling methods were rarely validated and evaluated. As one of the standard tests to characterize the biomechanical properties of long bones, mid-shaft bending test was chosen as the scaling scenario since relatively large amounts of data were available.

Scaling method assumed a geometric similarity between the objects scaled from and to, so the response of the target was predicted by the known base using the ratios of the fundamental properties (e.g. length, mass, and material properties). Mass-based scaling method assumes constant mass density between the scaled objects. A length scale factor is normally calculated by taking the cube root of the ratio of the segment mass or body mass. Structure-based scaling, however, considers the structures of the interested body regions. When applying structured based scaling method for long bones that normally failed under bending, the model of a simply supported Euler–Bernoulli beam was proposed. The structure-based scaling method assumes constant strain at outermost surface between the scaled objects.

*Cadaveric humerus and femur mid-shaft bending test data from literature were used as data sources. specimen data including cross-section geometry properties, specimens mass or body mass, young's modulus or related information (e.g. BMD, ash fraction) were required. Both scaling methods were applied to scaling fracture moment and force-deflection response between these specimens. A procedure was proposed to evaluate the scaling results. Statistical significance tests between different scaling methods were also conducted using the Student *t*-Test. Finally, correlation analysis between the resulting fracture load forces, moments, deflections with respect to the cadaver bone cross-sectional properties, body mass, mineralization were conducted.*

The results show that the structure-based scaling method didn't generate more accurate fracture moment than mass-based scaling method, with the directional percentage errors averaging 7% (humerus) and 14% (femur) for the mass-based, and even slightly higher 11% (humerus) and

21% (femur) for the structure-based. Both methods resulted in large standard deviation because of the large variability associated with biological specimens. Correlation analyses showed that: For humerus, there was no significant relationship between section modulus (I/c) and failure moment ($R^2=0.047$); for femur, the correlation coefficient between the section modulus (I/c) ($R^2=0.39$) and failure moment was basically the same as that for body mass ($R^2=0.40$).

However, structure-based predict more accurate results in following situations: 1) when the bending tests had constant span length, structure-based scaling method predicted more accurate force-deflection responses, this is because structure-based scaling method also included the span length of the bending test as loading conditions. 2) When the specimens have unusual mass (e.g. obesity), structure-based method are better because mass-based method assume constant density. Estimation errors was expected to increase as the geometrical differences between the objects increase, future efforts will be necessary to fully compare these scaling methods in a wider range of sample size when more biomechanical data are available.