STEPWISE MICRO-COMPRESSION AND IMAGE-GUIDED FAILURE ASSESSMENT OF RAT FUNCTIONAL SPINE UNITS

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Introduction
The spine is subjected to repetitive, cyclic loading during the course of ordinary daily activities. If this repetitive loading is of sufficient magnitude or duration, fatigue failure of the bone tissue may result. Clinically, trabecular fatigue fractures are observed as compressive stress fractures and are often preceded by buckling and bending of microstructural elements.

Whereas osteoporotic fractures are typically defined as 20-25% reductions in vertebral height, bone yields at about 1% strain; thus, bone tissue is damaged in the post-failure region long before an osteoporotic fracture is said to have occurred. Yet few attempts have been made to assess the bone mechanics beyond initial yielding and failure.

Past studies involving vertebral compression have been primarily concerned with the elastic (pre-yield) behavior of the bone, characterizing bone by its quantitative biomechanical parameters such as Young’s modulus, energy absorption, yield point, and ultimate failure point. Few studies have mechanically tested an intact lumbar vertebra under physiological loading in compression.

Micro-computed tomography (µCT) is an emerging technique to nondestructively image trabecular bone in three dimensions. A method of testing uniquely available to micro-computed tomography is that of stepwise, rather than continuous, compression. A micro-compression device, or MCD, is used to image loaded specimens directly in the µCT.

The bone specimen can be subjected to successively increasing compressive loads and imaged at each load step, allowing a dynamic assessment of bone failure.

In this project, we demonstrate and validate an image-guided approach to the biomechanics of rat functional spine units (three consecutive vertebrae) to illustrate the high potential of µCT to monitor and analyze failure on the whole bone level in a noninvasive fashion.

Methods
Eight weight-matched Sprague-Dawley rats (225-250 g) were used for this study. The rats were stored in a freezer at –20°C; then were allowed to thaw before dissection. The L3-L5 functional spine unit was excised. Adhering soft tissue was removed manually from the vertebrae; allowed to thaw before dissection. The L3-L5 functional spine unit was Eight weight-matched Sprague-Dawley rats (225-250 g) were used for this study.

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Discussion
Most research dealing with compression of vertebral bone has involved testing a section of a single vertebra in the elastic range and statically assessing its mechanical properties. The methodology developed in this study is more physiological and more edifying than prior efforts because it changes four of the methods traditionally used in testing. First, three consecutive vertebrae were used so that the two outer vertebrae could exert a more physiological load on the middle vertebra. Second, the post-failure behavior, rather than the elastic behavior, was the focus of the analysis. Third, the data analyzed was highly qualitative and image-driven, rather than merely quantifying mechanical parameters. Finally, µCT is used to assess dynamically damage accumulation and fracture progression.

µCT images from this study reveal bending and buckling of trabecular elements, followed by complete fracture of the trabeculae. Macroscopically, damage is seen throughout the trabecular structure. The images also confirm that closing of the gap between the vertebral body due to compression of the intervertebral disc is the low values of εg.

In summary, a methodology for stepwise compression of whole rat vertebrae has been developed and validated for a small number of specimens. More data will be needed before a final assessment of the validity and comparability of the new testing method is possible. Nevertheless, the ability to look “inside” a structure while it is failing is a powerful one, and is worth investing more effort.

The use of nondestructive imaging techniques in assessing trabecular changes should lead to improved understanding of the effect of bone quality (architecture, mineralization, etc.) on bone strength. This understanding will, in turn, lead to greater understanding of the importance of bone quality in the etiology of spontaneous fractures of the spine and, ultimately, to more successful approaches to the prevention of these age-related fractures.

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