INTRODUCTION

Loads experienced by the spinal column are transferred from one vertebral body to the next through the intervertebral disc (IVD) and the vertebral endplates. Prolonged repetitive loading is likely to influence the biological and mechanical response of the vertebrae as well as the IVD. A rat tail model allows for the study of interactions between IVDs and vertebrae in vivo because of its accessibility. A related study of the IVD found dynamic compression increased anabolic metabolism with some accumulation of early IVD degeneration under prolonged dynamic compression [1]. An improved understanding of the relationship between bone and IVD remodeling in early degeneration may improve interpretation of clinical pathologies and may help inform tissue engineering strategies.

The aim of this study was to identify major changes of bone mass and mineral density in rat caudal vertebrae subjected to dynamic compression loading using an Ilizarov-type apparatus. We hypothesized that the applied dynamic compressive load could increase the volume and density of loaded vertebrae. The overall goal is to detect early changes in vertebrae in response to loading and to relate those alterations with IVD remodeling.

METHODS

Two carbon fiber rings were attached to caudal vertebra c8 and c9 of fourteen skeletally mature Sprague-Dawley rats (12 weeks old) with two orthogonal sterile 0.8-mm Kirschner wires per ring, spanning the caudal disc c8-9 [2]. Rats were divided into a loading group (n=7, rings attached, cyclic compression applied) and sham group (n=7, rings attached, no loading applied). A specially designed pneumatic loading apparatus [3] applied sinusoidal compression loading with a peak magnitude of 12.6 N at a frequency of 1 Hz corresponding to an effective stress of 1 MPa. The compression was applied for 8 hours a day for 8 weeks. Animals were euthanized 24 hours after the last loading cycle, and the c6 (unpinned control) and c8 (pinned loaded) vertebrae were harvested and fixed in ethanol. The samples were scanned at an isotropic resolution of 12 μm using a microtomographic imaging system (μCT 40, Scanco Medical, Brüttischen, Switzerland). The long axis of the vertebral body was oriented orthogonally to the axis of the X-ray beam. In order to investigate differences between the vertebral bodies (unpinned c6 vs. pinned c8) and compare the effect of dynamic loading (loaded vs. sham) a volume of interest 1.2 mm thick (i.e. 100 slices) between the location of the most caudal pin and the caudal endplate was defined. Analysis was performed for the total cross-sectional area. Total volume (TV), bone volume (BV), apparent density (AD) bone mineral density (BMD) and cortical thickness (CortTh) were obtained. Analysis of variance was used to determine significant differences (p<0.05).

RESULTS

The TV, BV as well as CortTh of pinned c8 vertebrae significantly increased for the loaded groups with respect to sham (p = 0.008, p = 0.004 and p = 0.015, respectively), while their BMD significantly decreased (p = 0.05). The unpinned c6 vertebrae of the loaded group also demonstrated a significant increase in TV and CortTh compared to the sham group (p = 0.045 and p = 0.042), while their BV and BMD did not vary (Fig.1). The value of TV showed a substantial, but not significant increase for c8 vertebrae (p = 0.060), while their BV and CortTh increased and BMD decreased significantly (p = 0.001, p = 0.022, p = 0.002) compared to the unpinned c6 vertebrae. No differences were measured between vertebra levels of shams (Fig. 1).

DISCUSSION

As hypothesized, daily exposure to dynamic compression induced changes in vertebral bone structure (Fig. 1, Fig. 2). A substantial increase in bone volume was accompanied by a reduced degree of tissue mineralization in the loaded vertebrae: evidence of a fast, not yet completed, functional adaptation of the structure to the new mechanical environment (i.e., the new bone is not yet fully mineralized). Significant effects of vertebral level (pinned vs. unpinned) were mainly detected in the loaded group suggesting remodeling effects were due to loading and not the surgical procedure. However, pinning effects and growth during the experimental period could also have some effects. Further analyses are necessary to characterize remodeling effects in more details, including endplate and trabecular bone changes. We conclude that increased vertebral bone volume is an early response to prolonged dynamic compression. In the context of the prior study on IVD remodeling, we also conclude that bone and IVD both remodel in response to dynamic compression, and further understanding the interrelationship between vertebral and IVD remodeling in early degenerative processes is warranted.

Figure 1: Total volume (TV), bone volume (BV), apparent density (AD) bone mineral density (BMD) obtained with the microCT.

Figure 2: Cross-sections of loaded and sham C8-vertebrae with corresponding CortTh (mean and standard deviation in mm)

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