Response of the Intervertebral Disc and Subchondral Bone to In-Vivo Dynamic and Static Loading

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INTRODUCTION

Each year, low back pain (LBP) affects about one in two individuals in the US population, and is associated with an estimated $194 billion in medical costs and lost wages [1]. The clinical signs and symptoms of low back pain are well characterized, yet the etiology of the LBP remains unknown. While the causes of LBP are multi-factorial, epidemiologic data indicates a correlation between mechanical loading and degenerative disc disease, the most common cause of LBP [2]. Clinically, endplate sclerosis is observed concomitant to degeneration of the intervertebral disc [3]. It has been speculated that endplate sclerosis diminishes diffusion of nutrients into the intervertebral disc, leading to disc degeneration. The purpose of this study was to characterize and compare the response of the intervertebral disc and subchondral bone to dynamic (high and low frequency) and static loading in an in-vivo model.

METHODS

We have previously reported on our technique for applying controlled, cyclic axial loads to the New Zealand White rabbit spine in-vivo [4]. Cyclic axial compression was applied to the rabbit lumbar intervertebral disc for 2 hours/day, 5 days/week for up to 30 weeks. Forces equivalent to 5 x BW were applied at three frequencies (static, n=2; 0.5 cycles/sec, n=8; and 5.0 cycles/sec, n=4). At the conclusion of the loading period, each rabbit in the cyclic loading group was administered 0.3 mmol/kg of gadodiamide, then euthanized and imaged using a 7T MRI. Sagittal images for T1 relaxation mapping were acquired using a RARE sequence to assess diffusion of gadodiamide into the disc. µCT analyses of all animals were conducted to quantify changes in subchondral bone density. All specimens were used for histologic analysis, and were stained with Safranin-O and Fast Green, or hematoxylin and eosin.

RESULTS

MRI results indicate that cyclic compression correlates to a longer T1 constant, indicative of less diffusion into the disc. This trend was more pronounced in animals loaded at 5.0 Hz than 0.5 Hz. µCT analyses illustrated an increase in subchondral bone density in animals that underwent dynamic loading, a trend that was not evident in statically loaded animals, as seen in Figure 1. The increase in bone density correlated with the increase in T1 constant in dynamically loaded animals. The extent of histologic changes to the intervertebral disc was also dependant on frequency, as shown in Figure 2.

DISCUSSION

The results from this study indicate that dynamic mechanical loading leads to an increase in subchondral bone density, which is correlated to a decrease in diffusion into the intervertebral disc. Furthermore, the changes to the intervertebral disc and subchondral bone appear to be dependent on frequency. In our model, static loading has affected the disc only and not the adjacent endplates or subchondral bone, as indicated by µCT and histologic analyses. Low rate loading at 0.5 cycles/sec seems to have stimulated a remodeling response in the disc and endplates, characterized by an increase in subchondral bone density and small decreases in diffusion, as well as mild histologic changes. High rate loading at 5.0 cycles/sec appears to lead to chronic degeneration of the disc and more advanced sclerotic changes to the endplates. Substantial matrix disorganization, fibrosis and loss of disc height are evident from histologic analyses, in addition to an increase in subchondral bone density and corresponding reduction in passive diffusion.

The disc is a viscoelastic structure, and therefore exhibits rate dependant deformation. The apparent rate-dependent response of the disc and endplates to different may be mediated by rate-induced differences in nutrient transport to the disc. Future work will be aimed at elucidating the effects of different loading rates on net transport into the intervertebral disc, as well as the biologic response of the disc to high and low loading rates.

SIGNIFICANCE

This study indicates that harmful mechanical loading is an initiator of intervertebral disc degeneration. The response of the disc and endplates to loading is highly rate-dependent, with high rate, low rate and static loading causing very different responses in the disc and endplates. High rate loading appears to initiate sclerosis and degeneration, low rate loading initiates remodeling of the disc, while static loading is detrimental to the disc but does not appear to affect subchondral bone. Future work will be aimed at better identifying the underlying mechanisms behind these processes.

REFERENCES


Figure 1. An increase in subchondral bone density was observed in dynamically loaded levels, a trend that did not occur in statically loaded animals.

Figure 2. Mid-sagittal histologic sections of surgical control (upper left), 26 week low frequency loading (upper right), 30 week high frequency loading (lower left) and 48 week static loading (lower right). Sections are stained with Safranin-O and Fast Green. Images are 2X.