MECHANICAL FUNCTION OF RODENT LUMBAR AND CAUDAL DISCS: VALIDATION COMPARED TO HUMAN MOTION SEGMENTS IN AXIAL COMPRESSION

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INTRODUCTION

The intervertebral disc functions to distribute load, permit motion, and dissipate energy. With degeneration, the disc loses the ability to perform these functions. While the structural changes attributed to progressive degeneration have been fairly well established, the mechanisms for changes are poorly understood. Rodents are an often-used animal model to study the mechanisms leading to disc degeneration [5-9] because they are small, inexpensive, and easy to handle. In addition, the availability of genetically engineered mice is important to future studies. Despite their utility, the mouse and rat have not yet been established as functionally (i.e., mechanically) valid models of the human disc.

Some rodent models of degeneration have used the lumbar spine, and others have used the caudal (tail) spine [5-9]. The later studies utilized the tail due to its accessibility for applying in vivo mechanical loads or deformations locally. However, comparisons between the lumbar and caudal levels have not been made, and it has not been determined whether the caudal spine is a good mechanical representation of the human lumbar (or rodent lumbar) spine.

The aim of this study was therefore to establish mouse and rat disc as a valid mechanical model for human disc, and second, to compare the caudal and the lumbar levels. We hypothesized that: 1) because the mouse disc is similar in composition and structure to the human, it will also have similar material properties, and 2) because caudal segments experience significantly more motion than lumbar, caudal segments will be less stiff, but will have material properties similar to lumbar segments.

METHODS

Rodent Mechanical Testing

Lumbar and caudal spine segments were harvested from n=7 and n=8 mice and rats respectively. Segments were cleaned of muscle and soft tissue, facets were removed and radiographed such that measurements of area (the disc was assumed to be an ellipse) and disc height could be determined for each disc. Lumbar (L1/L2) and caudal (C7/C8) motions segments were then removed from the dissected segment, gripped with micro-vises and interfaced with an Instron 5542 uniaxial testing device. Mice motion segments were subjected to 20 cycles of +/- 0.5N (approximately 2X body weight) of uniaxial load at 0.1 Hz. Rat motion segments were also subjected to 20 cycles of +/- 3.5 N (approximately 1X body weight) at 0.1 Hz.

Normalization of Published Human Data

Human compression motion segment mechanical behaviors that had been previously reported were normalized for comparison to the rodent mechanics [1-4]. In axial compression, the stiffness (S, N/mm) was normalized as $\widehat{S} = Sh/A$, h=height and A=area.

RESULTS

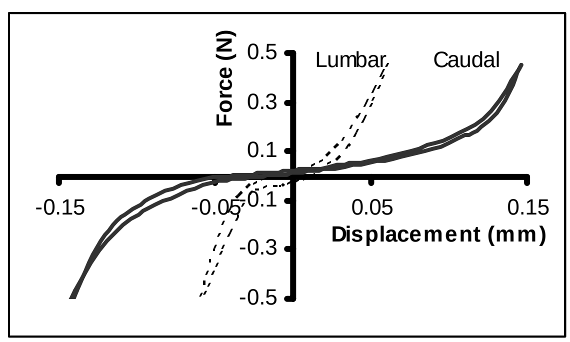

Figure 1: Typical tension/compression cycle

The force/displacement curve (Fig1) illustrates the differences in lumbar and caudal motion segments in one mouse. As seen in the figure, the caudal segments had more displacement over the same loads compared to the lumbar segments. The compression data from this cycle was then used to compute stiffness using a bilinear curve-fit. The break point between the two lines was used to define the 'toe region', the length of which is similar to the neutral zone. The slopes of these lines were then used for comparisons of stiffness between lumbar and caudal in both the toe and linear regions.

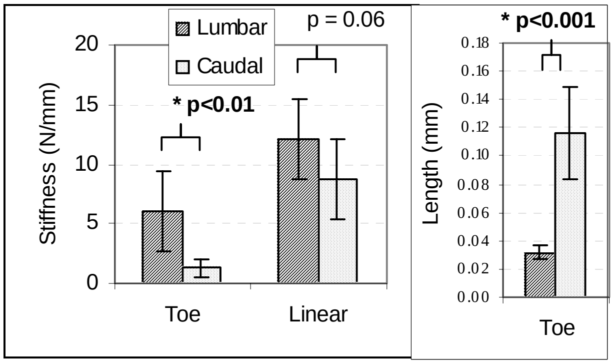

Figure 2: Stiffness and length of 'toe' region for lumbar and caudal rat motion segments.

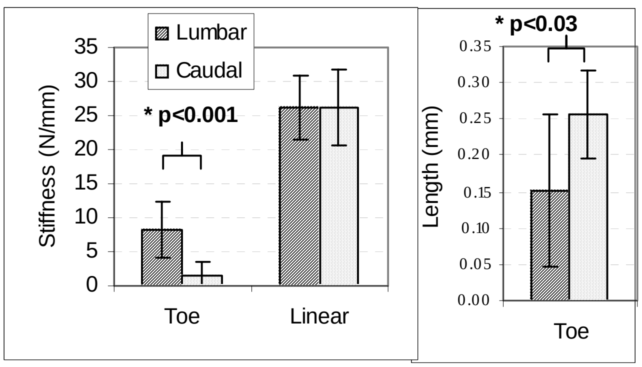

Figure 3: Stiffness and length of 'toe' region for lumbar and caudal mouse motion segments.

The average lumbar stiffness was greater than the caudal in both the toe and linear regions, but only in the toe region was this difference significant for both the rat and the mouse (Fig2 and Fig3 respectively). In addition, the length of the toe region for caudal segments was significantly larger than for lumbar again for both animals.

Finally, the areas and heights measured from radiographs were used to calculate normalized stiffness in the linear region for both mouse and rat motion segments. The mean +/- standard deviation of the normalized stiffness of both the rat and mouse lumbar and caudal motion segments were then compared to results reported for human lumbar motion segments as seen in Fig4 (where each number on the x-axis corresponds to a referenced paper).

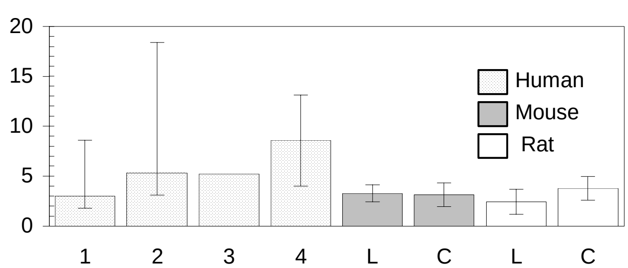

Figure 4: Normalized Compressive Stiffness (MPa) for Human Lumbar, Mouse and Rat Lumbar (L) and Caudal (C) Motion Segments

DISCUSSION

Comparisons with Human

The compression stiffness for both the lumbar and caudal motion segments, when normalized for disc height and area, were similar to lumbar mechanical data published on humans [1-4] (Fig4). Thus, as hypothesized, both mouse and rat motion segment compressive mechanical behaviors are comparable to human, suggesting the rodent disc is a valid mechanical model of the human disc. It should be noted that human motion segment data were normalized to the average disc height and area reported, whereas rodent disc stiffness was normalized for each segment tested, and the average reported.

Lumbar and Caudal

While the normalized stiffness of the lumbar and caudal segments was similar in the linear region, the lumbar stiffness was significantly larger (~ 3X) in the toe region of the load-displacement response for both animals (also known as the neutral zone). In addition, the length of the toe region (neutral zone) was much larger (~ 4X for the mouse) for the caudal segments as compared to the lumbar. Thus, whether or not the tail is an appropriate model of the lumbar spine depends on the relative importance of the neutral zone in disc mechanics. Work with other soft tissues, such as ligaments and tendons, indicates that in-vivo loads rarely surpass 40% of the maximum load of the tissue, suggesting that these tissues are largely loaded within the toe-region [10]. Assuming this holds true for the disc, then the neutral zone would play a significant role in disc mechanics; however, without knowing in-vivo loads acting on the disc, it is difficult to quantify this role.

Future Work:

In addition to measurements of elastic compression properties, we are examining tensile properties and viscoelastic properties such as hysteresis area and creep, for both the mouse and rat. We are also conducting torsion tests on both mouse and rat motions segments in order to validate that mechanical function is comparable to the human.

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