MECHANICAL DIFFERENCES BETWEEN MOUSE LUMBAR AND TAIL MOTION SEGMENTS ARE LARGEST IN THE TRANSITION ZONE

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INTRODUCTION:
Rodents are widely used models for studying disc degeneration. We recently conducted a validation study which confirmed that, when normalized for geometry, mouse and human lumbar mechanics were similar [1]. We also found differences in compression stiffness between lumbar and tail segments. The greatest use of the rodent tail as a model for studying mechanical pathways of degeneration [2-6], expanded analyses of the lumbar and tail mechanical differences are needed. The objective of this study was to examine the mechanical differences between lumbar and tail motion segments of the mouse under axial compression and tension loading. We hypothesized that the transition zone would be larger (i.e., more axial displacement) for tail segments due to the greater physiological motion experienced by the tail as compared to the lumbar spine. We also hypothesized that tail motion segments would be less stiff in compression due to the relatively higher loading of the lumbar spine in compression during ambulation [7].

METHODS:
A total of 8 two-month old C57BL/6 mice were utilized according to an approved IACUC protocol. Lumbar and tail spines were dissected, facet joints removed, and microradiographed to calculate disc height (anterior and posterior) and width (lateral and anterior-posterior), which were used to normalize mechanical data. Motion segments were prepared by making axial cuts through the L1/L2 (lumbar) and C7/C8 (tail) vertebrae.

The vertebrae were gripped by customized micro-vises and placed in a PBS bath in an uniaxial mechanical testing system (Instron 5542). Each motion segment was loaded in axial compression and tension according to the following protocol: the segment was cycled 20 times between 0.5 N of compression and 0.5 N of tension at 0.1 Hz (tension-compression cycle), compressed to 0.5N over 100 seconds (slow ramp), returned to zero load, and finally compressed to 0.25N over 1.0 second, and held for 30 minutes (creep).

The nonlinear mechanical data from the loading portion of the 20th cycle were analyzed using a tri-linear model to calculate the stiffness in three loading zones: compression, transition, and tension, as well as the displacement within the transition zone, which is analogous to the ‘neutral zone’ (Fig 1). Stiffness (S) was normalized using the equation: S = (h + D)/A, where h is disc height and A is area, assumed to be elliptical. Displacement (D) was normalized to the original disc height and reported as stretch = (h + D)/A. The stiffness of the slow ramp test was determined from a linear regression, and the decrease in disc height during the creep test was calculated. The lumbar and tail levels were compared using unpaired t-tests. Significance was set at p<0.05.

RESULTS:
The largest differences between lumbar and tail mechanics were in the transition zone, where lumbar segments were 2 times stiffer than the tail, and half the displacement length of the tail (Fig 1, Fig 2). In compression of the cyclic loading, there was a trend for lumbar stiffness to be greater than tail (3.65 ± 0.98 and 2.48 ± 1.09 MPa, respectively, p=0.1) and this difference was significant for the slow-ramp test (1.87 ± 0.5 and 1.21 ± 0.5 MPa). Lastly, stiffness in tension was not to be greater than tail (3.65 ± 0.98 and 2.48 ± 1.09 MPa, respectively, p=0.1) and this difference was significant for the slow-ramp test (1.87 ± 0.5 and 1.21 ± 0.5 MPa). Lastly, stiffness in tension was not significantly different between lumbar and tail segments (2.54 ± 0.4 and 2.16 ± 0.95 MPa).

During the creep test, lumbar motion segments compressed significantly less than tail following the initial application of load (77% of original disc height compared to 44% respectively, as seen in Fig 3). At the end of the creep test, the lumbar segments were also compressed much less than the tail (61% compared to 8% of initial disc height). Interestingly, both segments had the same average decrease in disc height (36%) at the same rate over the 30 minute creep test as seen in Fig 3.

DISCUSSION:
This study demonstrated that lumbar and tail motion segments of the mouse were significantly different in elastic and viscoelastic mechanics. Figure 1 clearly illustrates the large differences between lumbar and tail transition zone behavior, namely that the lumbar transition zone is much smaller and stiffer than the tail. Furthermore, these transition zone differences carry over into the creep results, in that the stretch at the beginning of the creep test for the lumbar segments (77%) was much larger than for the tail segments (44%). The additional 36% decrease in disc height due to creep for both segments resulted in a final stretch of 4% for the lumbar and only 8% for the tail. Thus, the larger and less stiff transition zone of the tail segments, led to nearly a total loss of disc height after 30 minutes of loading at 1X body weight.

These findings are particularly relevant to rodent tail models where chronic loads are applied in vivo to study mechanical pathways of degeneration [2-6]. Specifically, our results indicate that a static load of 1X body weight will produce drastically different strains in the lumbar and tail discs, which should be taken into account when interpreting results from in vivo studies. It is also important to keep in mind that our results are from lumbar segments without transverse processes and therefore differences reported here are likely to be even larger in vivo where intact lumbar processes would reduce the amount of creep under static loading. Therefore, while accessibility will continue to make the rodent tail an attractive model, our results show, based on creep and transition zone mechanical behavior, that the mouse lumbar motion segment more closely resembles the human.

REFERENCES:
1. Elliott DM, et al, Spine 2003(submitted);

ACKNOWLEDGEMENTS: The Whitaker Foundation