QUANTIFICATION OF SPINAL CORD DEFORMATION DURING ACUTE SPINAL CORD INJURY IN AN ANIMAL MODEL

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INTRODUCTION
Experimental investigation of spinal cord mechanics during injury has typically been limited to quantifying gross spinal cord morphology under extraneous applied loads. While this approach has been varied and utilized many times over the past decades, it is readily acknowledged that an appreciation for how the internal elements of the spinal cord deform, would provide a more appropriate perspective of the mechanical stimuli that causes acute spinal cord injury (SCI). In order to accomplish this, a novel, displacement-controlled, MR-compatible rig was designed, that is able to induce specific, repeatable spinal cord injuries in vivo, in a rat model, within an MR scanner. In this study, an image processing method was developed to quantify the deformation of the in vivo rat spinal cord during an acute SCI event. The processing method was evaluated for accuracy against a ‘gold-standard’ measure, and also evaluated for versatility, by employing the method across a number of varying SCI events.

METHODS
Animals (n=24) were anesthetized and inserted into a test rig to facilitate MR-imaging of the spinal cord. One set of MR images was acquired in the ‘uninjured’ state (7T Bruker-Biospec, Germany; T2-echo, 140x140um in-plane resolution, 0.5mm slice thickness). Then, an acute SCI was induced in the animal at the C5/6 cervical spine level, through a pneumatic actuator triggered from outside of the MR machine and sustained for the duration of the following MR scan (~30min). Four different ‘types’ of acute SCI could be induced: a light (n=6) or severe (n=6) contusion injury¹, or a light (n=6) or severe (n=6) dorsal dislocation injury¹. Once the injury was induced, another MR scan was performed to image the injured spinal cord. The ‘pre-injury’ and ‘injury’ MR image data sets were used as inputs to an image registration algorithm (Insight Segmentation and Registration ToolKit, ITK, US National Library of Medicine) that was constructed to compute the deformation field that represented the motion that the spinal cord must undergo during injury. The registration process consisted of rigid, affine and deformable transformations, effected by the use of optimization metrics. The output of this process is a deformation field that maps every pixel from the ‘pre-injury’ image set to their respective locations in the ‘injury’ data set. To evaluate the accuracy of this image processing algorithm, a validation study was performed that employed a ‘gold-standard’ method of measuring soft tissue motion. Aluminum oxide beads (~120um diameter, Brace GmBH, Germany) were injected into pre-determined positions in fixed, fresh cadaveric spinal cords that underwent one of the four aforementioned SCI injuries (n=4x3=12) with the same MR imaging methods performed. In this cadaveric model of SCI, the motion of the beads due to the injury could be calculated by comparing the ‘pre-injury’ and ‘injury’ locations of the beads. The image registration algorithm was then run on these data sets, and the portion of the deformation field that corresponded to the location of the injected beads was compared to the actual measured motion of the beads. An error measure encompassing the discrepancy between the actual 3D bead motion and the predicted motion was then ascertained.

RESULTS AND DISCUSSION
MR specimen data (example – Figure 1) is currently being analyzed and processed with the aforementioned image registration process. Qualitatively, the image processing algorithm appears to compare well with the measured motion of the injected markers, suggesting that validation of this image processing method is possible. Although deformation fields are obtainable from the in vivo experiments, a validation measure is required to ensure that the produced results are a true representation of how the spinal cord deforms during these induced injuries.

CONCLUSIONS
Measurement of in vivo, soft tissue deformation using image analysis methods would be of great importance to the study of SCI. The very sensitive and inaccessible nature of the spinal cord environment would make a non-invasive, deformation measurement technique very valuable to future studies.

REFERENCES

ACKNOWLEDGEMENTS
The authors would like to acknowledge NSERC for their support of this project.