Mechanical characterization of Spinal Cord Injury (SCI): tissue level thresholds in a rat model

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Introduction.

Very little is understood about the underlying biomechanics of stress and strain on the spinal cord resulting from an impact causing permanent injury. Animal models of contusion injuries have been shown to closely approximate a Spinal Cord Injury (SCI) in humans (1, 2). To this aim, we have conducted a computational study to examine the severity and the extent of SCI in the rat following force-defined impact. Tissue strain was targeted for the assessment of thresholds for injury and compared with histological findings (3, 4). We report that our FEM model enables predictions of injury extent and is a useful tool toward understanding the biomechanics of SCI.

Methods.

The C4 midline contusion was performed as described in Zareen et al. (2017) on seven Sprague-Dawley rats (female, 32 weeks old) using a 3.5 mm in diameter spherical impactor. A subset of animals were scanned using MRI (7.0 Tesla 70/30 Bruker Biospec, resolution 0.234 mm) and microCT (Siemens Inveon, resolution 0.196 mm), co-registered and segmented with ScanIP (Simpleware, Exeter, UK) for bone, dura mater, cerebral spinal fluid (CSF), white and gray matter. Model was imported in Abaqus (Simulia, v6.14-3) for FEM (~0.4M tetrahedral elements). Boundary conditions and the total time (T.t) for the simulation were assigned to match the experiment (impactor velocity, 122 mm/s; T.t., 0.135 s). Material properties were initially assigned according to Maikos et al. (2008) and fitted to the experimental reaction force curves using an inverse analysis in Abaqus. The combination of bulk modulus (K), shear modulus (G) and Poisson ratio (v) resulting into the best fitting was used for the FE analysis of the contusion SCI.

Results.

Probability density and cumulative distribution function were plotted for the strain. 90%, 95% and 99% of the cumulative probability was achieved respectively at 0.163, 0.174 and 0.193 strain. With the maximum limit of 0.19, the strain map from the simulation matched the histologic results of the rat injured spinal cord with higher strain values close to the lesion area.

Discussion.

The comparison of the results from the experimental animal model and the output of the FEM indicate that strain is a good predictor of tissue damage thresholds. Scaling the FEM model may be used to inform the biomechanics in human SCI.

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