Effect of Bone Fragment Impact Velocity by Burst Fracture on Biomechanical Parameters Associated to Spinal Cord Injury

Batbayar Khuyagbaatar, MS, Kyungsoo Kim, PhD, Yoon Hyuk Kim, PhD.
Kyung Hee university, Yongin-si, Korea, Republic of.

Disclosures: B. Khuyagbaatar: None. K. Kim: None. Y. Kim: None.

Introduction: About 15% of spinal cord injuries (SCIs) associated with traffic accidents or falls are caused by vertebral burst fractures. Bone fragments of the vertebral body are propelled into the spinal canal at high impact velocities, causing spinal cord damage and various degrees of neurological deficit. Several experimental and computational studies have investigated the effect of bone fragment impact on the spinal cord during trauma. However, the effect of the impact velocity of a fragment generated by a burst fracture on the stresses and strains inside the spinal cord which are known to be related to clinical symptoms or injuries has not been quantitatively investigated. In this study, a fluid structure interaction (FSI) model that included the spinal cord, dura mater, and CSF was developed and validated. The effects of bone fragment impact velocity on stress, strain distribution, cord deformation, and cerebrospinal fluid (CSF) obliteration were investigated to gain insight into the mechanisms underlying SCI.

Methods: A fluid-solid interactive dynamic three-dimensional finite element model of bovine spinal cord was developed based on experimental studies [1, 2], where the spinal cord model is consisted of the cord, dura mater, and CSF. The dural sheath was placed 1.5 mm from the cord, equal to the average thickness of the CSF layer [1] (Figure 1). Then CSF layer was demonstrated Newtonian fluid characterized by viscosity of CSF [3] using Eulerian-Lagrangian analysis technique. Material property of spinal cord was modeled using data from Hung’s study [4]. A single tangent modulus for the dura mater and material properties of the posterior wall and pellets were derived from Persson et al. [5]. Three types of pellets were used, which are same mass but different impact areas. The validity of the model was achieved from the results of the dynamic impact tests on the spinal cord by comparing the maximum deformations of spinal cord in the anterior-posterior direction and time to maximum deformation to those reported in previous experimental studies [1, 2]. The von-Mises stress distribution in the cord, the longitudinal strain, the cord compression and cross-sectional area at the center of the impact, and the obliteration of the CSF layer were analyzed for the three types of pellets at impact velocities of 1.5 m/s, 3.0 m/s, 4.5 m/s, 6.0 m/s, and 7.5 m/s using finite element analysis (ABAQUSSTM, ABAQUS Inc., Providence, RI, USA). Pearson’s correlation analysis was performed with a significance level of 0.05 to investigate how the impact velocity and the pellet contact area affected the results.

Results: The finite element model was validated with experimental studies [1, 2] by comparing of the maximum deformation of the whole spinal cord and maximum deformation cord within the dural sheath, and time to maximum deformation of whole spinal cord. The von-Mises stress, longitudinal strain, cord compression, reduction in cross-sectional area, and obliteration of CSF were each significantly correlated to impact velocity (Table 1). The von-Mises stress in the cord increased as the impact velocity increased, and the maximum value increased dramatically when the velocity of the pellet exceeded 4.5 m/s (Figure 2a). Cord compression and reduction in cross-sectional area were directly proportional to the impact velocity (Figure 2c and 2d). The longitudinal strain and obliteration of
the CSF also increased gradually as the impact velocity increased (Figure 2b and 2e). The maximum stress in the cord peaked in the center of the cord for all velocities and pellets.

**Discussion:** In the study, the maximum stress in the spinal cord increased substantially when the initial impact velocity of the pellet exceeded 4.5 m/s, regardless of the size of the pellet. In addition, the longitudinal strain, cord compression, reduction in cross-sectional area, and obliteration of the CSF increased gradually as the velocity of the pellet increased. Present study supported by fact that neurological deficits appear when the cross-sectional area is reduced by 30%; and cord compression about 50% was associated with neurological damage [6, 7]. The average cord compression of 43% and reduction in cross-sectional area of 31% at the pellet velocity of 4.5 m/s in our study also support the suggestion that the 4.5 m/s could potentially be regarded as a threshold for possible pathological deficits in the cord. Moreover, several biomechanical parameters including longitudinal strain, cord compression, cross-sectional area, and obliteration of the CSF were within the possible injury risk range.

**Significance:** The present study predicted injury risks based on biomechanical parameters associated with SCI and provided insight into the mechanisms underlying SCI.

![Cross-section of spinal cord model](image)

**Table 1.** Correlation coefficients between biomechanical parameters and pellet parameters.

<table>
<thead>
<tr>
<th></th>
<th>Impact velocity</th>
<th>Impact area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>p-value</td>
</tr>
<tr>
<td>von-Mises stress</td>
<td>0.88</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Longitudinal strain</td>
<td>0.82</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cord compression</td>
<td>0.95</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>
Reduction in CSA 0.97 < 0.001 -0.17 0.527
Obliteration of CSF 0.79 < 0.001 -0.53 0.038

Figure 2. (a) Maximum stress, (b) maximum strain, (c) cord compression, (d) reduction in cross-sectional area, and (e) obliteration of the CSF for three types of pellets at velocities of 1.5 m/s, 3 m/s, 4.5 m/s, 6 m/s, and 7.5 m/s.

ORS 2015 Annual Meeting
Poster No: 1551