

The role of the cerebrospinal fluid in traumatic spinal cord injuries

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INTRODUCTION

Burst fractures of a vertebral body, due to e.g. falls or traffic accidents, account for 15-30% of traumatic spinal cord injuries. The initial mechanical insult due to the impact between a bone fragment and the spinal cord may cause secondary biological damage. Despite the risk of severe consequences such as permanent paralysis, the knowledge of the initial mechanical insult is limited.

Previous research has found that neural tissue damage is related to the amount and rate of deformation of the tissue [2,3] and an *in vitro* study found that the cerebrospinal fluid (CSF) surrounding the cord has an important role in limiting the deformation of the cord during impact [4]. However, due to the closed nature of the system, an evaluation of strain distributions within the cord is difficult to achieve during *in vitro* testing. Also, difficulties regarding tissue handling and degradation makes the use of a computational model an attractive alternative for parametric studies.

The aim of this study was to develop a fluid-structure interaction model of the impact between the bone fragment and the spinal canal.

METHODS

The computational model was aimed at reproducing *in vitro* tests of the impact between a simulated bone fragment and detached bovine spinal cord [5]. Tests were performed on cord surrounded by dura mater and CSF, cord plus dura mater only and finally on the bare cord. Data from these tests was used to validate the model.

The finite element software package ADINA[®] (ADINA R&D Inc., Watertown, MA) was used to build a three-dimensional model of the impact. ADINA[®] permits the direct coupling of the solid and the fluid model, using the conditions of displacement compatibility and traction equilibrium at the interface. In the structural model 8-noded elements were used whereas 4-noded elements were used in the fluid model. The spinal cord and the dura mater enclosing the cerebrospinal fluid were modelled using non-linear material models based on previous experimental studies on the spinal cord [6,7,8]. The cerebrospinal fluid was modelled as a Newtonian fluid using properties previously defined for saline solution. The Total Lagrangian formulation was used to solve the equations using an implicit integration method.

RESULTS

The finite element model gave similar results to the experiments in terms of maximum cord deformation. However, the time to maximum deformation and duration of deformation were significantly lower in the computational model, as shown in figure 1.

In accordance with the experimental results, the model gave a decrease in cord deformation due to the presence of the cerebrospinal fluid. The finite element model also

uncovered a different displacement pattern to that assumed during the experimental tests. In the experiments, complete subdural collapse was believed to occur prior to any deformation of the cord. However, the computational model showed that the cord deformed anteriorly before complete collapse of the fluid layer and then posteriorly after all fluid had been pushed away, giving rise to two peaks of deformation instead of one.

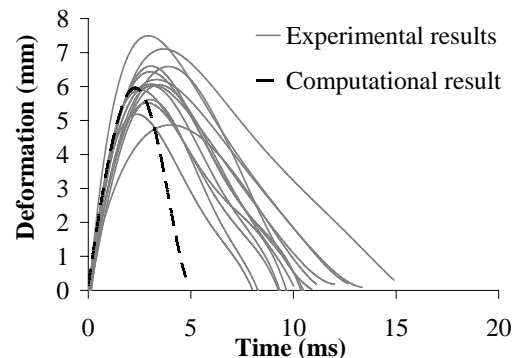


Figure 1. Deformation of the bare cord during impact.

DISCUSSION

Although maximum deformations were found to be similar to the experimental results, the computational model failed to reproduce the displacement pattern of the bone fragment over time. Further investigations are required to enhance the current models to allow the accurate representation of the temporal as well as displacement features of the interaction.

The results indicated that the cerebrospinal fluid is important in limiting the deformation of the spinal cord during trauma. Also, the value of computational models in studying the biomechanics of closed systems was apparent: the actual displacement pattern of the cord identified through the computational model was not detected in previous *in vitro* studies.

The anatomical simplicity of the model is a limitation of the study: epidural contents, longitudinal ligaments and nerve root attachments between cord and dura mater were not included. Although these components may have an effect on the amount of deformation of the cord, the relative results are still considered valid.

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