A C2–C3 FINITE ELEMENT MODEL TO DETERMINE THE STRESS PATTERNS OF ODONTOID LOADS

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INTRODUCTION

Reports have indicated that more than 60% of traumatic spinal cord injuries involve the cervical spine, and approximately one out of five cases of all cervical spine injuries involve the C2 vertebra [1,2]. The most common axis injury is odontoid fracture, of which the majority is Type II or dens fracture [3]. These injuries occur at the dens–body juncture, resulting in potentially disastrous instability. Though a great volume of literature detailing the epidemiology and management of Type II fractures exist, only a few analytical studies have been conducted to investigate the biomechanical loading paths of dens fracture [4,5]. Of those that exist, a major assumption and limitation was the full constraint boundary conditions applied to the inferior aspect of the C2 vertebra model. As such, the axis was unable to displace with the rest of the cervical spine column during load application. This is contrary to physiological conditions, where the mobility of the C2–C3 joint is likely to provide some level of stress relief [4]. On such a basis, a previously reported C2–C3 osseoligamentous finite element model [6] was exercised under different loading conditions to investigate the stress trends associated with Type II fractures.

MATERIALS AND METHODS

The three-dimensional, nonlinear FE model of the C2–C3 complex was generated from human cadaveric data. The model comprises the C2 and C3 vertebrae, the single juxtaposed intervertebral disc and all biomechanically important ligaments (**Figure 1**). Material models for the various spinal components were obtained from the published literature. To evaluate the stress distributions in the odontoid process during Type II injuries, pressure loads were applied on the dens at locations where it is likely to come into contact with the surrounding neck construct. Such contacts may arise from the impaction of the dens with the anterior arch of the atlas, transverse ligament and/or the medial aspect of the lateral masses of the C1 vertebra. Therefore, pressure loads on the surface of the dens were sequentially varied from the posterior to anterior directions at 45^{o} intervals in five load cases to characterize stress patterns (**Figure 2**). The equivalent force magnitude for each iteration was 100 N. The inferior vertebral body of C3 was rigidly constrained in all directions. FE analysis was performed on the ANSYS 6.0 platform.

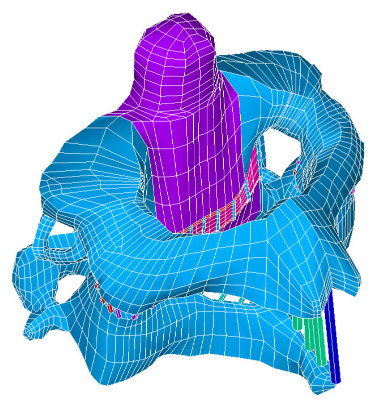
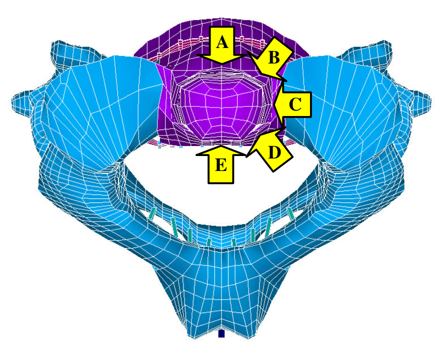


Figure 1. Finite element model of the C2–C3 segment.



Load case	Loading direction
A	posterior
B	postero–medial
C	medial
D	antero–medial
E	anterior

Figure 2. Schematic depicting the pressure load variation on the body transverse plane.

RESULTS AND DISCUSSION

Maximum principal stress contours on the C2 vertebra, with accompanying peak stresses and their locations, were plotted and studied, as fracture initiation and propagation is attributed to the greatest tensile stresses (**Figure 3**). The results showed that peak stresses were located at the dens–body juncture, towards the anterior side for a straight posterior load (case A) and towards the lateral side for the other four cases. Peak stress showed an increasing trend as the load deviated from straight posterior loading. That of a straight anterior load (case E) (41.0 MPa) was about three times as high as that of a posterior–medial load (case B) (13.9 MPa). For posteriorly-directed loads (cases A and B), the highest stresses were distributed transversely across the dens–body juncture, whereas for the other three cases, the greatest stresses were bi-directionally distributed, transversely across the dens–body juncture as well as inferiorly into the body. Furthermore, as the loading became more anteriorly-directed, the stresses became more concentrated inferiorly. This may arise from the articulations of the zygapophysial joints as the respective components of C2 rise up/down ipsilaterally/contralaterally against the C3 vertebra.

All these observations imply that less force is necessary to produce Type II fracture of the axis when loaded in the anterior direction. Moreover, high stresses induced on the C2 vertebral body at loading in the medial to anterior range may possibly point to a change from a Type II to a Type III stress pattern.

CONCLUSION

For the first time, a C2–C3 finite element model has been developed and exercised under varying load conditions to investigate stress patterns on the odontoid process. Though the model is not expected to fully explain the mechanisms behind Type II and III injuries, it nevertheless permitted the partial elucidation of stress transmission through the axis. The model demonstrates that the direction of the load vector is an important determinant for the occurrence of dens fracture. In addition, stress relief accorded by the C2-C3 junction may have resulted in reduced stress magnitudes across the C2 vertebra during load application.

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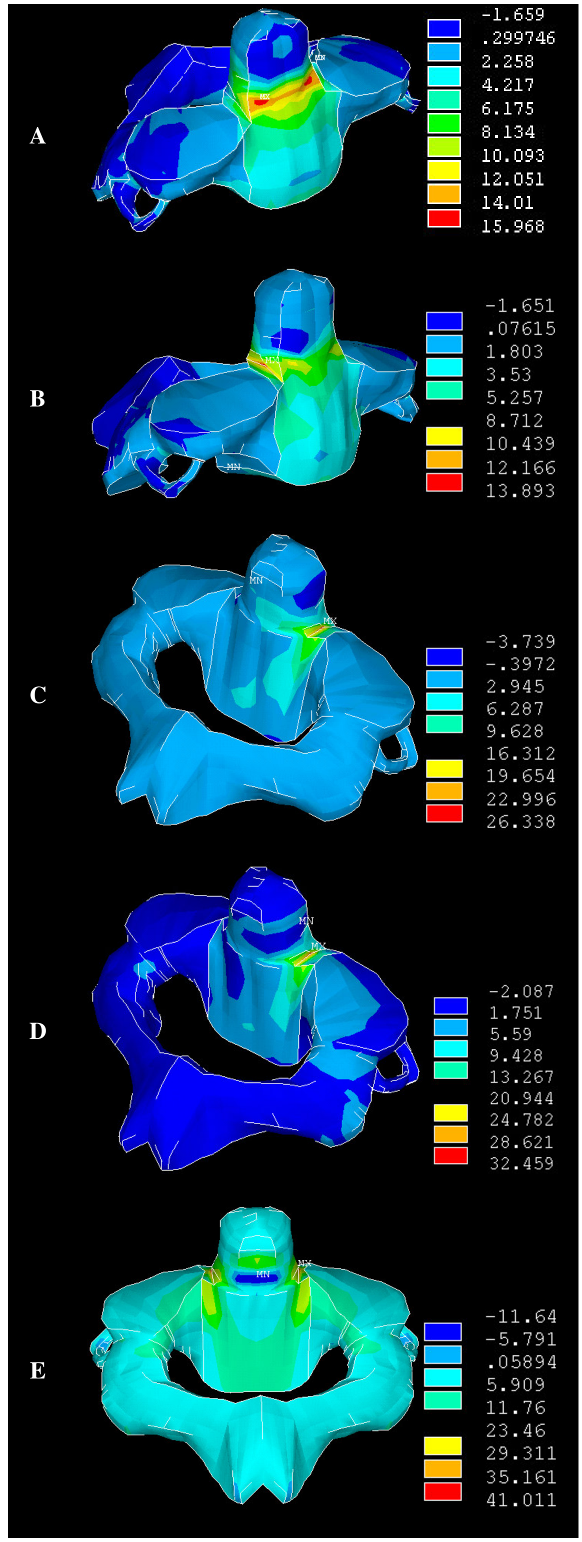

Figure 3. Maximum principal stress contours on the C2 vertebra with accompanying peak stress locations upon application of the various load cases.