Finite Element Analysis Of The Cervical Stability after Ligamentous Injuries

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Introduction
The cervical spine is often subjected to many types of loading during daily activities. Stability of the cervical spine is provided by ligaments, facet joints, muscles and disc, which restrict the range of movement. Many biomechanical studies on the injured and stabilized cervical spine have already been carried out by other authors 1-7. There are also finite element analyses of the cervical spine instability due to facetectomy and laminectomy to provide further understanding 8,9. However, the contribution of ligaments to cervical spine stability has not been clearly established. Ligaments provide stability to the cervical spine motion and thus, an important part of cervical spine research. Ligamentous injuries will decrease the mechanical stiffness the cervical spine, and potentially affecting other spinal components. It is clear that a cervical motion segment is unstable if it exhibits abnormally large displacements in terms of either rotational or translational movements under physiological load levels.

In 1983, Maiman conducted a study to determine the force required to produce ligamentous injuries under compression, flexion and extension 2. The effect of ligamentous injury on motion segment flexibility under sagittal moments has been studied in vitro by Wen et al., 1993 5.

For the clinicians, it is important to know if there is sudden large increase in the motion segment flexibility during different levels of ligamentous injuries. Knowing this information will help the surgeons to decide whether to fuse the segment or not. Addressing this question in-vivo using animals models would be impractical as there are notable anatomical differences between the animal model and the human cervical spine. In-vitro experiments is time consuming and sometimes not possible to perform over all possible combinations of ligamentous injuries. Analytical models, on the other hand, can be used to perform a study on the effect of any combination of ligamentous injuries on motion segment flexibility. The finite element method is well suited for this purposed.
The purpose of this research was to establish and validate three-dimensional normal and injured models of the cervical spine capable of simulating ligamentous injuries under a wide range of physiological loading modes.

**Material and Methods**

Four finite element models of the normal and injured spinal motion segment C4-C6 and C5-C6 shown in Figure 1 were developed for instability studies based on a 68 year-old cadaveric cervical spine. Two C5-C6 (normal and injured) models were created by removing the C4 vertebrae and its associated soft tissues. This is necessary for the validation due to the limited *in-vitro* studies carried out to determine the stiffness of the cervical spine. The normal models were analyzed and validated according to the setups and loadings carried out by *in-vitro* experiments \(^{10,11}\). Ligamentous injury models were constructed from the normal models through the resection of ligaments and compared against experimental results under sagittal moments \(^5\). Due to the absence of information and results under compression, anterior and posterior shear, the validated injured model is then extended to investigate these modes. The material properties of the spinal components were assumed to be linear, homogeneous and isotropic. Therefore, only the Young’s modulus of elasticity and the Poisson’s ratio were used \(^{12}\).

![Figure 1: Iso-posterior view of the a C4-C6 finite element model](image)

**Results**

The predictions of biomechanical force/displacement response and rotational angle of the finite element models are presented here. Figure 2 shows the comparison of the normal models against *in-vitro* results under seven physiological loading modes. Figure 3 shows the comparison of the injured models against *in-vitro* results. Take note there are no *in-vitro*
studies conducted under compression, anterior and posterior shear. Results shows that that compression, anterior shear, extension and lateral bending are least affected by ligamentous injuries.

![Graph showing force-displacement and motion changes](image)

**Figure 2:** Validation of the normal models. a) C4-C6; b) C5-C6 models.

![Graph showing force-displacement and motion changes](image)

**Figure 3:** Validation of the ligamentous injured model. a) C4-C6; b) C5-C6 models.

**Discussions**

Spinal instability often has been characterized as a condition in which abnormal motions at the segmental levels are observed in response to the physiological loads. Damage to the spinal cord or nerve roots, injury and pain are sometimes included with clinical definitions of instability.

We believe that the ligamentous tissue is one of the major components providing stability to the human cervical spine. Therefore, the primary objective of this study was to assess the role of ligaments in resisting physiological loads. Prior to the injuries study, the model was validated under most physiological loading conditions. Since a validation for the
ligamentous injured model has never been reported in the literature previously, this study, for
the first time, underscores the importance of having a fully validated normal and injured
model.

These models will be extended to investigate, understand and offer new explanations and
findings on the effects of ligamentous injuries on other spinal components, such as
intervetebral disc bulge, intra-disc nucleus pressure.

Conclusions
The validated injured model represents essential advancement in comparison with previous
finite element models of the cervical spine, making it possible for such models to be used in
investigating ligamentous injuries. These results provide new insight through injury
simulation into the role of the ligaments in providing cervical spinal stability.

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