CERVICAL INTERVERTEBRAL DISC INJURY MECHANISMS DURING SIMULATED WHIPLASH

Manohar M. Panjabi, Shigeki Ito, Adam M. Pearson and Paul C. Ivancic

Biomechanics Research Laboratory, Yale University School of Medicine, New Haven, CT, USA
E-mail: paul.ivancic@yale.edu

INTRODUCTION

Although clinical studies have thoroughly documented the occurrence of cervical disc injury in whiplash patients, there is a lack of biomechanical studies investigating the injury mechanisms of the intervertebral disc during whiplash. Thus, the goals of this study were to use the whole cervical spine model to determine the annulus fibrosus fiber strain and disc shear strain during simulated whiplash and compare these values with corresponding physiological data.

METHODS

Six fresh-frozen human osteoligamentous whole cervical spine specimens were mounted at the occiput and T1. Movie flags, each with two white, spherical, radio-opaque markers, were attached to each vertebra. A lateral x-ray of each specimen was used to develop geometrical rigid body relationships between the centers of the flag markers and points on the vertebral bodies (VBs) used to calculate the intervertebral disc deformations. The intact specimens underwent flexibility testing up to peak loads of 1.5 Nm to determine the physiological disc deformations.

To prepare a specimen for whiplash simulation, a surrogate head was attached to the occipital mount. The surrogate head and spine were stabilized using the compressive muscle force replication system (Ivancic et al., 2002).

Rear-impact whiplash simulations were performed using a bench-top sled apparatus at nominal T1 horizontal accelerations of 3.5, 5, 6.5 and 8 g (Panjabi et al., 1998). High-speed digital cameras recorded the spinal motions at 500 f/s.

The anterosuperior (point 1) and posterosuperior (point 5) corners of the lower VB of each functional spinal unit from C2-C3 to C6-C7 were selected on the x-ray (Figure 1). Three additional points (points 2, 3 and 4) evenly spaced between points 1 and 5 were also selected. The endplate coordinate system x-y had its origin at point 1, its positive x-axis was oriented posteriorly through point 5, and its positive y-axis was orthogonal to the x-axis and oriented superiorly.

The annulus fibrosus fibers were oriented posterosuperiorly at 30° to the x-axis (referred to as the 30°-fibers), with origins at points 1, 2 and 3 and insertions at the inferior surface of the upper VB (points A, B and C). Three points (1’, 3’ and 5’; not shown in Figure 1) were selected on the
inferior surface of the upper VB such that points 1’, 3’ and 5’ were directly superior to points 1, 3 and 5, respectively. The points were used to calculate the disc shear strain (\( \gamma \)) at each of the three points:

\[
\gamma = \arctan \left( \frac{\Delta x}{y_0} \right)
\]

where \( \Delta x \) and \( y_0 \) represented the x-axis translation and original disc height, respectively.

**RESULTS**

The peak 30°-fiber strains first exceeded physiological levels (\( p < 0.05 \)) during the 3.5 g simulation at C4-C5 (Figure 2). At 5g, significant increases spread to C3-C4, C5-C6, and C6-C7. The highest strains tended to occur in the posterior fibers. Peak fiber strain generally increased with increasing acceleration and reached a maximum of 51.4% in the posterior fiber of C5-C6 during the 8 g simulation.

![Figure 2](image)

**Figure 2.** Average peak 30°-fiber strains in the anterior (Ant), middle (Mid), and posterior (Post) annulus fibrosus fibers.

Peak disc shear strains exceeding physiological levels were observed throughout the C5-C6 disc during the 3.5 g simulation and spread to C4-C5 and C6-C7 at 5 g (Figure 3). In general, the disc shear strain increased with increasing impact acceleration. The greatest disc shear strain occurred at the posterior region, reaching a maximum of 1.0 radian at C5-C6 during the 8 g simulation.

![Figure 3](image)

**Figure 3.** Average peak disc shear strains at the anterior (Ant), middle (Mid), and posterior (Post) disc regions.

**DISCUSSION AND SUMMARY**

The current study demonstrated that excessive 30°-fiber and disc shear strain occurred during simulated whiplash. These strains were greatest at the posterior region of the C5-C6 disc, and clinical data suggests that this is the most common location for disc herniation in whiplash patients. While disc injury may be the cause of acute pain and muscle spasm following the trauma, it could also lead to disc degeneration, facet osteoarthritis and chronic neck pain.

**REFERENCES**


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