# Motion analysis of cervical vertebrae during whiplash loading

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STUDY DESIGN: The motion of each cervical vertebra during simulated rear-end car collisions was analyzed.

OBJECTIVES: To clarify the mechanism of zygapophysial joint injury during whiplash loading.

SUMMARY OF BACKGROUND DATA: The zygapophysial joint is the suspected origin of neck pain after rear-end car collision. However, no studies have been conducted on the mechanisms of zygapophysial joint injuries.

METHODS: Ten healthy male volunteers participated in this study. Subjects sat on a sled that glided backward on inclined rails and crashed into a damper at 4 km/hr [2.48 m/h]. The motion of the cervical spine was recorded using cineradiography. Each vertebra's rotational angle and the instantaneous axes of rotation of the C5-C6 motion segments were quantified.

RESULTS: C6 rotated backward before the upper vertebrae in the early phase; thus, the cervical spine showed a flexion position (initial flexion). After C6 reached its maximum rotational angle, C5 was induced to extend.

As upper motion segments went into flexion, and the lower segments into extension, the cervical spine took an S-shaped position. In this position, the C5-C6 motion segments showed an open-book motion with an upward-shifted instantaneous axis of rotation.

CONCLUSIONS: The cervical spine is forced to move from the lower vertebrae during rear-end collisions.

This motion completely differs from normal extension motion and is probably related to the injury mechanism.

KEY POINTS FROM THIS STUDY:

1) A double-blind, controlled study for chronic neck pain after whiplash injury found the facet joint as a source of the pain in 54% of patients (1995).

2) There is strong physiologic evidence that painful injuries to the facet joints occur in whiplash and are common.

3) In this study, the motion of the cervical vertebrae was recorded in live humans during simulated rear-end car collisions using cineradiography. The motion of each cervical vertebra was analyzed to investigate the mechanism of facet joint injury.

4) Surface electromyography was used over the sternocleidomastold and paravertebral muscles to record electromyographic activities during impact.

5) Cineradiography was used to record the cervical spinal motion during impact.

6) To quantify the segmental motion during impact, the positions of the instantaneous axis of rotation (IAR) were measured.

7) After impact, C6 rotated more quickly than the other segments.

8) "C5 began extension after C6 reached maximum extension, whereas the upper segments were still in flexion, causing the cervical spine to take an S-shaped position. At approximately 150 msec, while the bending moment to the neck reached its peak value, the C5-C6 motion segment, located at the convex of this S curvature showed the greatest extension compared with other motion segments, and this motion segment assumed an appearance similar to that of an open-book motion."

9) "The IAR moved upward in the crash motion compared with that in normal motion."

10) "The torso motion caused the cervical spine to move from the lowest vertebra to the upper vertebrae. The C6 extension motion began before that of the upper cervical vertebrae, and this time-lag caused the cervical spine to flex temporarily (initial flexion)."

11) Crash IARs moved upward to the C5 vertebral body so that the posterior edge of the C5 inferior articular facet appeared likely to collide with the C6 facet surface. "This facet motion was completely different from that during normal motion."

12) After the C5 facet collided with the C6 facet, the motion segments moved in an open-book motion.

13) "A compression and extension force (bending moment) applied to upper vertebrae is likely to be concentrated in the lower motion segment (C5-C6). This concentrated force acted as a rotational torque on C5, forced the stretching of the anterior longitudinal ligament, and forced the inferior articular facet to collide with the superior facet of the lower vertebra. If this bending moment is large enough, this motion is likely to cause the disruption of the disc from the vertebral rim (rim lesion) or to cause a zygapophysial joint injury."

14) "Most whiplash injuries occur during low-speed rear-end collisions and rarely produce morphologic changes such as fracture of the joint. The zygapophysial joint is a synovial joint and has a synovial fold (meniscus), between the articular facets that is innervated with nociceptive receptors. Thus, we hypothesize that facet collisions are likely to impinge on and inflame the synovial folds in the zygapophysial joints, causing neck pain (facet synovial fold impingement syndrome)."

15) "Acceleration data observed in this study are similar to those in a study using actual vehicles. Therefore, we consider the simulated sled to represent the same dynamic condition that occurs in actual rear-end car collisions."

**INVITED POINT OF VIEW**

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1) Recent research (1991, 1993) has shown that facet injuries were common in victims of fatal motor-vehicle accidents, and that these injuries were undetectable on plain radiographs.

2) Studies (1995, 1996) showed that zygapophysial joint pain is very common in patients with chronic neck pain after whiplash.

3) A 1997 study showed that the psychological distress suffered by chronic pain whiplash patients disappeared when their pain was relieved.

4) This study "fills a critical gap in the story of cervical facet pain. It provides the missing biomechanical link. Their's is the most significant advance in the biomechanics of whiplash since the pioneering studies of Severy et al in 1955. As a result of this study, we no longer rely on inference or speculation; we have a direct demonstration of the mechanism of injury in whiplash."

5) "The critical observation is that in whiplash the lower cervical segments undergo sagittal rotation about an abnormally high instantaneous axis of rotation. As a result, there is no translation; there is only rotation. As the vertebra spins, its anterior elements separate from, while the posterior elements crunch into, the vertebra below. This mechanism predicts that the resultant lesions should be tears of the anterior annulus and fractures of the zygapophysial joints or contusions of their meniscoids. These are the very lesions seen at postmortem."

6) "The threshold for symptomatic injury is approximately 8 kmph [5 mph]. When subjected to such impact, volunteers do develop symptoms. Given these data, it seems reasonable to expect that patients subjected to impacts four and eight times as great could develop lasting injuries and symptoms."