Three-Dimensional Motion Analysis of the Cervical Vertebrae during Lateral Impact

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Introduction
Mild neck injuries due to traffic accidents are caused by lateral impact as well as rear-end impact, but the mechanism of these injuries has not been clarified yet. We had performed motion analysis of the cervical vertebrae by using X-ray cineradiographic images, but the analysis was difficult because lateral bending of the cervical spine had the three-dimensional motions accompanied by flexion-extension and rotation (coupling motion).

We analyzed three-dimensional motions of the cervical vertebrae when the lateral impact was given, and investigated the mechanism of neck injury caused by lateral impact by comparing with motions of the cervical vertebrae during voluntary lateral bending.

Material and Method
This study was approved by the ethical committee at University of Tsukuba (No.254, 2003).
The subjects were 6 healthy adult volunteers. The frontal-view images of cervical vertebral motion during active lateral bending of the neck and lateral impact was applied were obtained using an X-ray cineradiography (60 frames/second). The lateral impact was applied to the right shoulder of subjects in a sitting position by using an air-impactor (Figure.1), and the impact load was 500-600N for men and 500N for women. In addition, biplane X-ray images of the cervical vertebrae were obtained. The center of the right pedicle (Point 1), the center of the left pedicle (Point 2) and inferior end of spinous process (Point 3) were regarded as 3 feature points (Figure.2), their coordinates in the three-dimensional space were obtained, and the distances between each point were calculated. Points 1 and 2 were considered to be the center of the rectangle tangent to the image of pedicle of vertebral arch in the frontal view, and to be the posterior edge of the vertebral body in the sagittal view. Point 3 was regarded as the midpoint of lower hem of the rectangle tangent to the shade of spinous process frontally X-ray cineradiographic image, and was scaled and rotated to fit in the three feature points on the cineradiographic image; and three-dimensional rotation angles of each vertebra between two consecutive frames were obtained (two-dimensional projection method). Using the above method, we analyzed lateral bending, flexion-extension and rotation motions at C4-Th1 segments whose feature points could be identified on the frontal X-ray cineradiographic image during voluntary lateral bending of the neck and lateral impact was applied.

Results
When the lateral impact was applied, lateral bending angles were changed by 7.5±3.5° at C6-C7 segment with 500N lateral impact (Fig.3), and 4.7±0.3° at C7-Th1 segment with 600N (Fig.4); which were greater than those made during voluntary lateral bending (5.2±2.1° and 3.0°±0.6°, respectively). The coupling motion indicating a flexion and an axial rotation in the same direction as lateral bending, as well as lateral bending motion of the cervical vertebrae, was observed at C6-C7 and C7-Th1 segments during voluntary lateral bending. However, when lateral impact of 500N was applied, an extension motion and an axial rotation motion in the opposite direction to lateral bending occurred at the C6-C7 segment. For the 600N impact, the similar motion was observed at C7-Th1 segment.

Discussion
During lateral impact, the lower adjacent cervical vertebra showed the lateral bending without coupling motion which surpassed the magnitude of the motion observed during voluntary lateral bending. This non-physiological lateral bending might cause compressive load in the facet joint of the side given the impact and tension stress in the joint of the opposite side; which might involve in the injury occurrence of facet joints.

Conclusion
When the lateral impact was applied, non-physiological lateral bending, which was not accompanied by the coupling motion observed during voluntary bending motion, occurred in subaxial cervical spine; which might cause the injury of facet joints.

Figure.1 Sequential images obtained from the experiments

Figure.2 Feature points