INTRODUCTION: Cervical spinal cord injury without fracture or dislocation has been experienced clinically in a fall, a traffic accident and so on. It was supposed that hyperextension of the neck caused this injury because most patients had lacerations or contusions on their faces. It was also suggested that contusion of the spinal cord was sustained at segments in narrow spinal canal with spondylotic changes. The latest studies using magnetic resonance images, however, revealed that cervical spinal cord injury without bony damage occurred predominantly at C3-4 where there was usually less spondylotic change. Therefore we hypothesized that the cervical spine would show some motion other than extension and that the impact force concentrated on C3-4 after a direct face impact. We analyzed the motion of each cervical vertebra during a direct face impact to clarify the mechanism of the spinal cord injury.

METHODS: Five healthy male volunteers with average age of 25 were seated on a specially designed chair. Low-level impact loads were applied backward to the maxilla of them via a strap. With each volunteers, cervical vertebral motions were taken by means of x-ray cineradiography at a speed of 60 frames per second (Cine-system: Philips BH5000, Cine-Camera: nac Arritechno 35) under impact loading condition. The images were recorded on CD-ROMs and the boundary lines between the cortex and background were dotted using graphic software (Canvas 7.02, Deneba System, Inc.) on a personal computer. The dotted points were used as templates and superimposed on the cervical vertebrae of each images. The angles in relation to the horizontal plane were calculated from the positions of the anterior-inferior points and the posterior-inferior points of each vertebral templates using a mathematics software (Mathematica, Wolfram Research, Inc.). The shear and axial forces and the moments at the head were calculated using the measured applied load, inertial properties of the head, and the translational and angular acceleration of the occipital condyle. The Ethics Committee of Tsukuba University approved the protocol of the experiments in advance.

RESULTS: In our experiment, posterior shear force to the head occurred at about 20 msec to 180 msec and reached the maximum force at about 70 msec. There was a little axial load of the head. Figure 1 shows the rotational angles of each vertebra in relation to C7. After impact, occiput and C1 were flexed immediately. After they reached the maximum flexion at about 110 msec, their
motions shifted to extension. C2 began to be flexed at approximately 40 msec. And after C2 reached the maximum flexion at about 130 msec, it shifted to extension motion. On the other hand, C4, C5, C6 showed only extension motion after the impact. That is, occiput, C1, C2, and C3 were flexed at initial phase (initial flexion) and shifted to extension, while C4, C5, C6 continued extension during impact load to the face. The cervical spine showed dual curvature which had an inflection point at C3-4 around 130 msec.

CONCLUSIONS: Our main concern is why cervical spinal cord injury without fracture or dislocation occurs frequently at C3-4 level where spinal canal is relatively wide. Taylor suggested that the factor which impinged on the cord was the forward-bulging ligamentum flavum during hyperextension. But this theory seems to be not enough to give an account of the mechanism because the lesion of the spinal cord injury in most of the patients is only one segment. In our experiment, most applied impact load to the face resulted in posterior shear force to the head. Occiput, C1, C2, and C3 were thrust backward in flexion (flexion-translation). Therefore the cervical spine showed dual curvature which had an inflection point at C3-4. We speculate that an actual impact to the face forces the cervical spine into the similar motion and greater shear force results in the posterior translation of C3 relative to C4 to cause spinal cord compression (Figure 2).

![Figure 1. Rotational angle of each vertebra relative to C7](image-url)

Figure 2. Motion of cervical spine during a direct face impact