Head-Neck Kinematics During Car Impact in Multi-planes

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Abstract – A detailed three-dimensional head-neck FE model was developed based on the actual geometry of a human cadaver specimen. Five runs were performed to simulate the responses of the head-neck complex under rear-end, front, side, rear-side and front-side impacts. Under rear-end and front impacts, the overall and segmental rotation displayed nearly axisymmetric curvatures. The primary rotational angles of neck under these two conditions are higher than those under other conditions. Under rear-side and front-side impacts, the coupling torsions were significant. For the capsular strains, the greatest value occurred under side impact. The peak capsular strain under front impact was higher than that under rear-end impact. The results show that the current model can reasonably reflect the response of the head-neck complex under various impact conditions. The effects of the impact direction on the kinematics of the cervical spine are significant.

Keywords: Head-neck biomechanics; impact; segmental rotation; kinematics; capsular strain

1 Introduction

The cervical spine is frequently injured during motor vehicle accidents (MVAs). In MVAs, a low-speed 8-mile/hour rear-end collision can produce a 2G acceleration of the vehicle and a 5G acceleration of the head within a span of 300ms or less. The energy imparted to spinal tissues in this short span of time may cause acute and chronic pain in soft tissues (ligaments, muscles, etc.). These injuries may not be immediately evident or demonstrable using general clinical assessment methods (computed tomography, magnetic resonance imaging or X-rays). Many of the cervical injuries are severe and may lead to permanent disability. Deeper understanding of the underlying mechanisms of vehicular cervical trauma may lead to improved methods of prevention, diagnosis, and treatment. Accordingly, in this study, a detailed three-dimensional C0-C7 FE model of the whole head-neck complex developed and validated previously was used to investigate the intervertebral kinematics responses of the head/neck complex under various simulated impact conditions.

2 Methods

A 3-d FE model of the C0-C7 reported previously was used for this study [1]. Briefly, the 3-d FE model of the head and cervical vertebrae were developed with geometrical data based on the actual geometry of a 68-year old male cadaver specimen. A flexible digitizer was used to capture the coordinates of the surface profile of the bony structures (head, C1-C7) continuously and these data were subsequently processed for the FE mesh generation. For the modeling of the intervertebral discs (IVDs), the basic geometries taken from the average values reported in literature [2] were used. Furthermore, the major ligaments and muscle groups associated with the cervical spine were also incorporated in the model, for which the attachment points were determined from anatomic text. Figure 1 shows the final C0-C7 FE model consists of 21,765 elements and 29,066 nodes and the global XYZ coordinate system. The material properties of the elements representing the skull and vertebrae were assumed to be elastic and perfectly plastic, homogenous and isotropic. The ligaments were modeled using nonlinear link elements, which only permit tensile axial force transmission to simulate the actual characteristic of human ligaments. For the muscles, only passive effects of muscle materials were considered. The material properties of various components were derived from literature [3]-[5]. For the impact simulation, a trapezoidal acceleration history shown in Figure 2, which was adapted in experimental study conducted by Ewing et al[6], was applied on the inferior surface of C7 vertebral body.

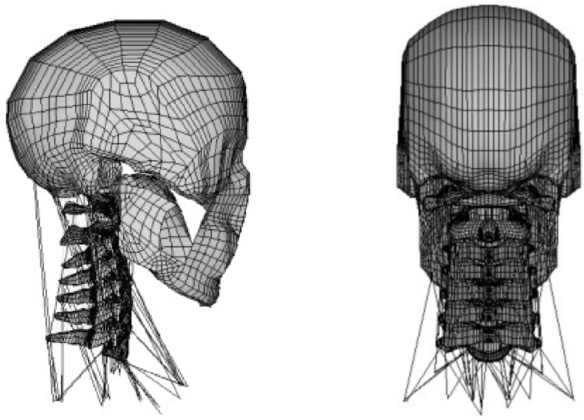
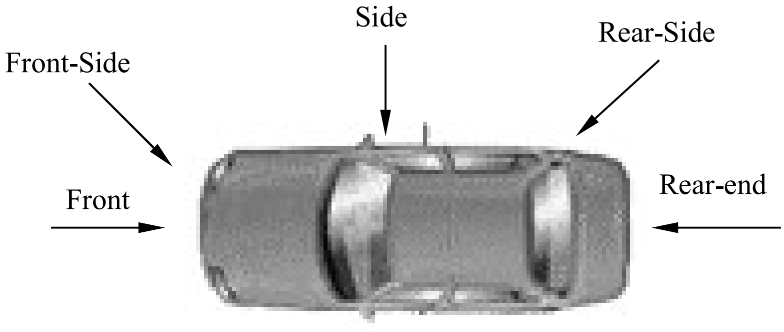


Fig.1 FE model of the C0-C7 (lateral and posterior views)



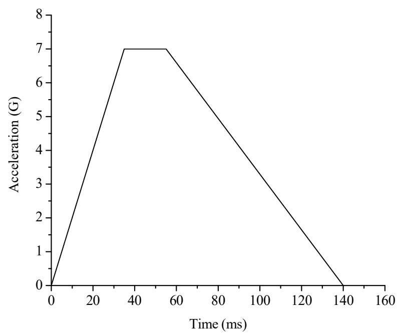


Fig.2 The simulated impact conditions. (a) Impact direction; (b) Input acceleration on C7 inferior surface

3 Results

Figure 3 shows the primary variation of head (C0) rotations with respect to the lowest cervical vertebra (C7) with time in sagittal and frontal planes. Under front, front-side, rear and rear-side impacts, the C0-C7 FE model predicted that the head translated horizontally for about 30ms without rotation (Figure 3a). Then the head began to flex or extend depending on the impact directions, and shows almost symmetrical rotations of C0 with respect to C7 in the sagittal plane about a frontal plane (Figure 3a) and with peak rotation at about 110ms with magnitude greater than 40^{o}. Under side and oblique impacts, the head translated laterally and obliquely about a transverse plane about 20ms without rotation (Figure 3b), then the head began to flex in the same direction at different magnitude opposing the impact directions. Under side, rear-side and front side, peak head rotation occurred at less than 100ms with magnitude below 28^{o}. Figure 3b also shows that the head changed direction of rotation (back to 0^{o}) occurred at about 100, 130 and 135ms under front-side, rear and rear-side, respectively.

Figure 4 shows the predicted typical variation of intervertebral rotations of C0-C1 and C6-C7 in sagittal (Figure 4a) and frontal planes (Figure 4b) under front/rear impact and side impact direction, respectively. Under front and rear impact, the C0-C7 FE model predicted the upper cervical segment C0-C1 changes from extension to flexion at about 75ms and from flexion to extension at about 62ms, respectively (Figure 4a). The lower cervical segment C6-C7 showed continual flexion rotation and reached peak rotation at about 130ms in front impact. In rear impact, C6-C7 continues extension rotation and reaches peak rotation at about 120ms. The intervertebral rotations analyses (Figure 4a) show the instant S-shaped and subsequent C-shaped curvatures of the head neck complex in sagittal plane under front and rear impact, and agree well with simulated whiplash study. However, under side impact (Figure 4b), the simulation shows, for the first time, that the head neck complex also exhibits S-shaped and C-shaped curvatures in its primary frontal motion. Initially, the upper C0-C1 segment experienced no rotation for about 10ms then began to rotation in one direction for about 30ms, and changed to opposite rotational direction for about another 98ms before changes in rotational direction again. Concurrently, C0-C7 experienced continuous rotation in one direction for about 140ms before changing direction.

Figure 5 shows the difference in the variations of the peak capsular strains for different impact conditions. The trends of the curves were quite different from those of the segmental rotations shown in Figures 3 and 4. Although C6-C7 level experienced the greatest rotational angle under all the five impact conditions, the motion segments suffered the peak capsular strain under rear, front and front-side conditions were C5-C6, C4-C5 and C4-C5, respectively. Despite the nearly symmetric rotational angles (Figure 3a) under front and rear impact, the peak capsular strain under front impact was 39% higher than that under rear impact. The highest peak strain occurred under side impact, which was followed by front-side and rear-side impact. The predicted peak strain under side impact was about 2.4 times higher than the peak strain under rear impact.

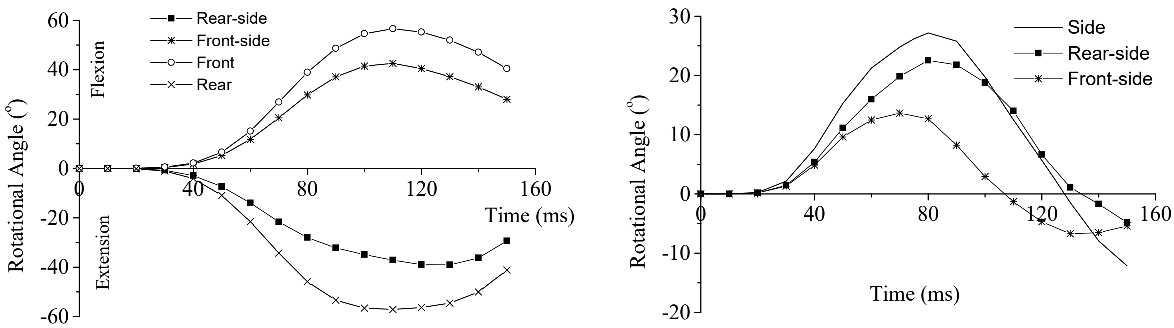


Fig.3 Predicted rotational angles of C0 respect to C7 under various conditions.
(a) In saggittal plane; (b) Under lateral bending

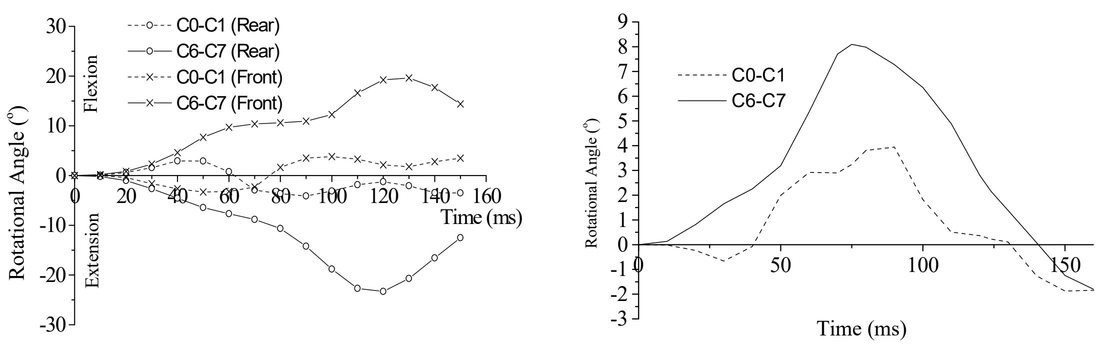


Fig.4 Predicted rotational angles of C0-C1 and C6-C7 under different impact conditions.
(a) In sagtittal plane under rear and front impact (b) Lateral bending under side impact

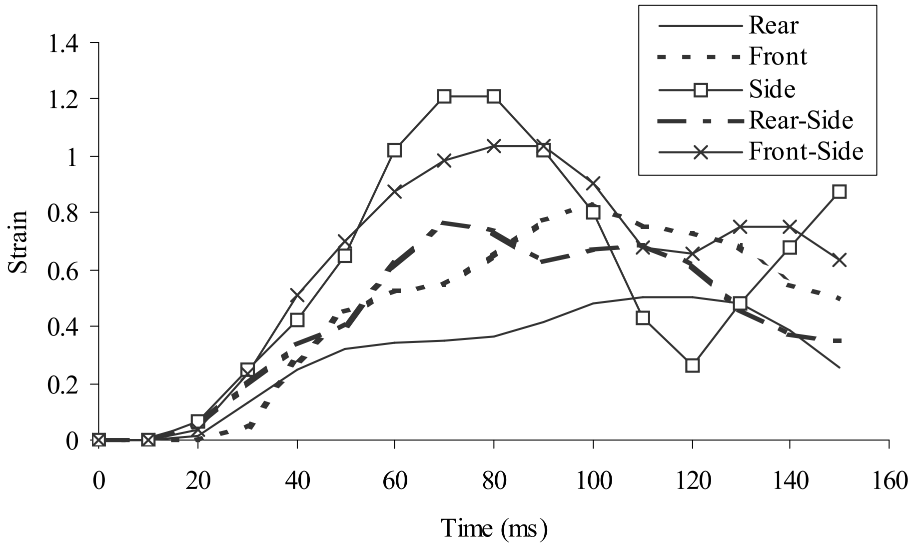


Fig.5 Predicted variations of peak strain in capsular ligaments during the impact

4 Conclusions

We have successfully used the previously developed C0-C7 FE model to characterize the post responses of the head-neck simulating the response of them under various impact conditions. The model behavior at simulated acceleration history compared favorably to data observed during whiplash simulation of volunteers under rear impact, and the extrapolation of the kinematics analysis of head and neck biomechanical response under other impact shows that S- and C-shaped curvatures, and relative smaller magnitudes of intervertebral rotation in frontal plane compare to those in the sagittal plane. Based on the simulated results the capsular ligaments seem to be at greater risk for injury under direct side and front-side impact.

5 References

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