Computer Simulation of Headrest Design Parameters and their Effect on Whiplash Injury Prevention

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Objective

Although traditional headrests are common in most passenger automobiles, they have resulted in only a 20 -30% reduction in whiplash injuries (Nygren 1985). In response to the limited effectiveness of traditional headrests, automobile manufactures have recently developed more advanced headrests and whiplash prevention mechanisms (Bigi 1998, and Viano 1993). The objective of this study was to develop a computer tool which can be used to provide design guidelines for whiplash prevention devices and evaluate the effectiveness of various approaches. Specifically a computer model of the cervical spine was developed, and a parametric study of headrest design parameters was performed, including headrest stiffness, damping, and initial head-headrest gap.

Methods

Computer Model of the Cervical Spine. Due to physiological complexity of the soft tissue in the cervical spine, it is currently difficult to generate a computer model accurate enough to simulate soft tissue injury directly. Computer models have been developed which include a significant amount of anatomical detail (DeJager 1994). However, due to insufficient knowledge of the dynamic properties of spine elements, it is difficult to make accurate predictions of spine injuries from the anatomical details in such computer models. Accordingly, for the purposes of headrest design analysis, a simplified Computer Model of the Cervical Spine (CMCS) was developed, which facilitates parametric studies due to a faster computer run time. CMCS simulates intervertebral motions of individual vertebra and the head. An injury criteria developed from experiments using cadaveric spines is then used to correlate intervertebral motion with spine injury (Panjabi 1999).

Each vertebra C1 to T1 and the head were modeled as rigid body, based on vertebral anatomy (Panjabi 1991). The adjacent vertebrae were joined by pin joints based upon *in vivo* data (Dvorak 1991). The intervertebral stiffness values were based on static flexibility testing of cadaveric spines, which include a low stiffness neutral zones followed by linear stiffness regions (Panjabi, unpublished). To account for dynamic stiffening, the static stiffness values were multiplied by a constant dynamic gain factor.

The mathematical model was implemented with the Working Model 2D software (Knowledge Revolution Co). The computer model was validated through comparison to results of *in vitro* whiplash tests. A dynamic gain factor of 4.0 was found to correlate head and vertebral motions of CMCS to the experimental results. Potential spine injury was evaluated using an injury criteria based on intervertebral motions (IV-NIC), (Panjabi 1999).

Headrest Design Parameters. One interpretation for the lack of effectiveness of traditional headrests, is that whiplash injury may occur before the head contacts the headrest (Panjabi 1998). Accordingly, a number of devices have been developed which move the headrest closer to the head during a rear-end collision in an effort to reduce the relative motion between the head and torso in a sufficient amount as to avoid neck injury. The relative motion between the head and torso depends on the dynamic properties of the headrest once contact is made with the head. Accordingly, the following headrest properties were evaluated:

G_{HR} – Gap between head and headrest (0 - 10cm)
K_{HR} – Stiffness of headrest (5 – 25 N/mm)
C_{HR} – Damping of headrest (0.2 - 1 Ns/mm)

Simulations were performed for T1 accelerations of 2, 4, 6, and 8g.

Results

Potential injury represented by IV-NIC is shown as a function of the headrest gap, G_{HR}, and impact acceleration in Figure 1, for K_{HR}=13 N/mm and C_{HR}=0.5 Ns/mm. In general IV-NIC increased with increasing impact acceleration. The headrest gap was shown to be an important design parameter, with significant injury potential occurring at only 4g acceleration when G_{HR} was 6cm. Parametric analysis of headrest stiffness and damping are shown in Figure 2, for an acceleration of 4g and G_{HR} of 4cm. Headrest stiffness above 5N/mm combined with headrest damping above 0.4 Ns/mm successfully reduced the magnitude of IV-NIC. Other simulations indicated that lower magnitudes of stiffness and damping did not significantly reduce IV-NIC, even with smaller headrest gaps. High stiffness headrest without significant damping were associated with high IV-NIC values during rebound of the head from the headrest.

Discussion and Conclusion

Computer simulations provide a valuable resource for the study of whiplash prevention devices. While experiments with human subjects and cadaveric specimens may provide a higher level of accuracy, they are time consuming and have lower repeatability. Accordingly, computer simulations are more suitable for parametric studies. The mathematical model, CMCS, was first validated in a limited way through comparison to experimental results and then used to study relevant headrest design parameters. Results indicated the combined importance of headrest stiffness, headrest damping, and headrest gap. CMCS does not have the anatomical detail of more sophisticated models (e.g. de Jager 1994), yet its simplicity enables more rapid computer simulation of numerous design parameters. Accordingly, CMCS provides a valuable design tool for the development and evaluation of whiplash prevention devices.

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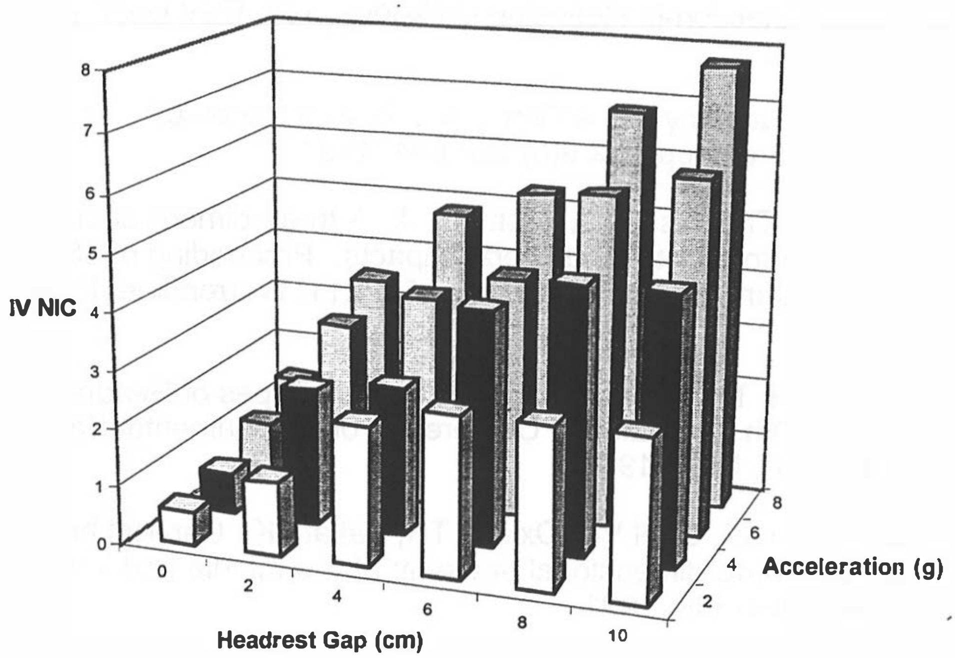
Effect of Headrest Gap and Impact Acceleration



Effect of Headrest Stiffness and Damping

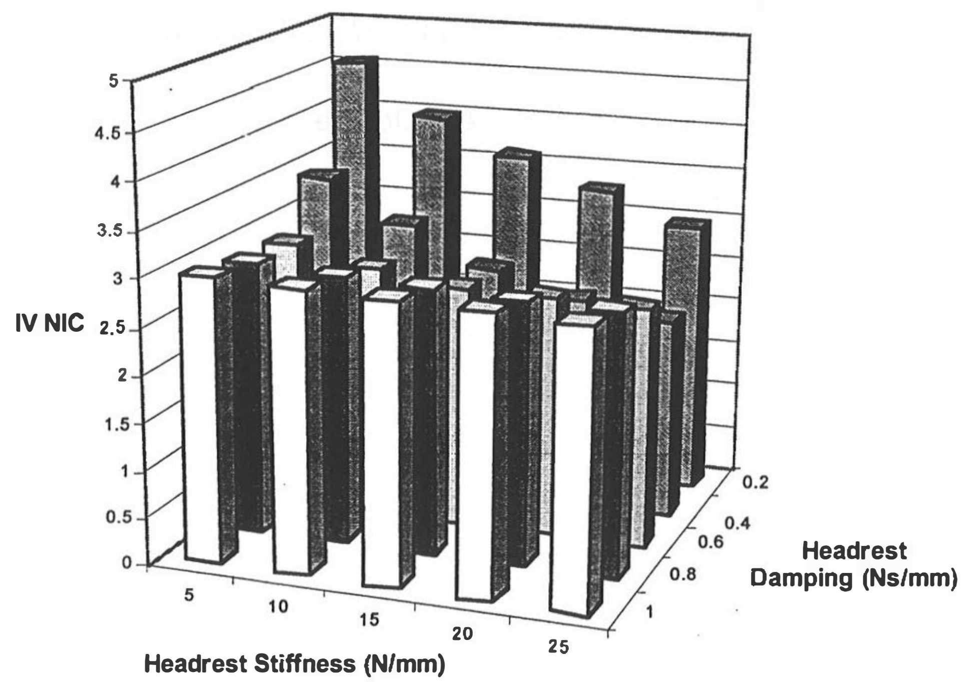


Figure 1 and 2: Parametric Analysis of Headrest Performance in terms of IV-NIC

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