RELATIONSHIP BETWEEN CERVICAL SPINE CURVATURE AND RISK OF INJURY IN THE CASE OF SAGITTAL IMPACT: A FINITE ELEMENT ANALYSIS

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INTRODUCTION

RISK OF INJURY AT THE CERVICAL LEVEL during automotive crashes is difficult to assess. Injury tolerance values were shown to be very dependent from intrinsic or extrinsic parameters and their relevance is still controversial. The curvature of the human neck presents a great variability (Matsumoto 1998) and may be influenced by a seated posture (Black 1996). The aim of this study is to assess the effects of various curvatures of the human cervical spine on the behavior of the neck submitted to frontal and rear-end impact using an omni-directionally validated three-dimensional FE neck model of a 50th percentile adult.

METHODS

The neck model is derived from Bertholon (1998) and is part of a complete human body model previously developed with the explicit finite element code RADIOSS. It represents the head and neck of a 50th percentile human seated in a reference position with a normal lordotic curvature. The geometry includes a volumic representation of the head, C3-T1 vertebrae, disks, soft tissues and muscles while C0/C1 and C1/C2 joints are modeled with non-linear 3D rotational spring-damper elements. Ligaments, articular capsules, skin and contacts between articular surfaces and spinous processes are modeled as well. Mechanical and inertial properties were taken from the literature.

An omni-directional evaluation was performed, comparing the kinematical results with those of impact tests (Ewing (1976) and other studies). Simulations of experimental injury tests were also performed in order to refine injury tolerance values taken in the literature. Then, the initial lordotic geometry was deformed into straight and kyphotic curvatures which were used in simulations, reproducing frontal (15g, 60km/h – *Fig. 1*) and rear-end impacts (7g, 25 km/h) from the studies referred above. Comparisons were performed in terms of kinematics, spinal deformation patterns, ligament elongations as well as forces and moments within each vertebral body for C3-T1 vertebrae or through the 3D rotational elements for C0-C2.

Fig.1 : Frontal impact simulation

RESULTS AND DISCUSSION

Results showed similar kinematical patterns in the initial phase and slight differences in the return phase. However, significant differences were found in the distribution and peak values of ligament elongations as well as forces and moments along the cervical spine for the three configurations.

FRONTAL IMPACT. Ligaments and discs: The ligamentum flavum elongation presents a peak value at C7T1 level *(Fig.2)* for the straight and kyphotic curvatures, while this is not the case for the lordotic one. For all curvatures, maximal disc strains are found at C3C4 level and C7T1.

Articular joints: Peak elongation values of the articular capsules are found at C7T1 level for all curvatures, with high values (up to 5.8 mm) in the cases of straight or kyphotic curvature.
Forces and moments: Initial extension moments are found in the upper level of the spine and greatest flexion moments through the vertebral body at the lower levels, significantly greater for the straight and kyphotic curvatures (up to 40%).

REAR-END IMPACT. Articular joints: Distribution of maxima of articular capsule elongation is quite different for the lordotic and kyphotic curvatures with respective peak values at C6C7 and C2C3. Inter-articular forces are maximal at C6C7 and C7T1 level with higher values for the straight and kyphotic curvatures.
Forces and moments: In rear-end impact, maximal extension moment at the lower level *(Fig.3)* is combined to important compressive forces (up to 1000 N) on the vertebral body. Again, moments are found to be significantly greater for the straight and the kyphotic curvature, indicating a possible increased risk of injury.

Fig. 2 : Frontal Impact : Maxima of ligament flavum elongation reached along the cervical spine

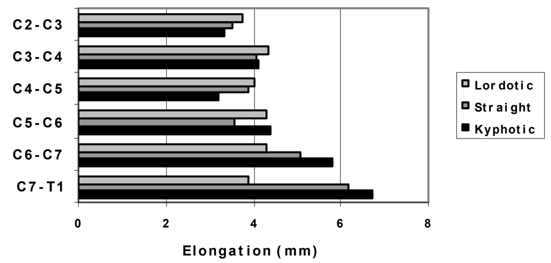
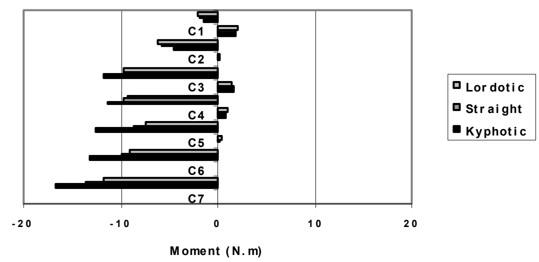


Fig. 3 : Rear-end Impact : Maxima of Extension/Flexion moment through the vertebral body along the cervical spine



SUMMARY

A detailed 3D FE model of the human neck was used to assess a possible relationship between risk of injury and curvature of the cervical spine in the cases of rear-end and frontal impact. Although no experimental results were found in the literature concerning such influence, some studies present an assessment of injury along the cervical spine following frontal or rear-end impact. In frontal impact, Kallieris (1991) found mainly intervertebral disc injury at C3-C5 level and lig. flavum tears at C6-T1 level. In the simulation, the kyphotic configuration was found more penalizing for this later mechanism of injury. This was also the case for the maximal flexion moments which may be related to vertebral body fractures found at the lower levels by the same author. Concerning the rear-end impact, Barnsley (1995) has described the articular joint as a possible source of pain after whiplash. Again, simulation results showed that a more kyphotic curvature yielded greater peak values of contact forces at the lower levels of the cervical spine. While keeping in mind that literature lacks possible comparison data, and although more validation and refinement of the model still may be performed, it was concluded that the variability observed on the curvature of the human cervical spine might have a significant influence both on the behavior and on the risk of injury of the neck during impact, tolerance values being potentially reached with one particular spinal curvature and not with another.

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