INTRODUCTION

Automobile rear crashes may cause injury to multiple anatomical structures of the cervical spine including facet joints and intervertebral discs. In attempt to reduce neck injuries during rear crashes, some current automobiles include anti-whiplash seats such as the Whiplash Protection System (WHIPS) or active head restraint (AHR). Occupant momentum pressing into the seatback during the crash activates mechanical-based systems integrated within the seat. The goals of this study were to determine facet joint and disc kinematics and ligaments strains of the lower cervical spine during simulated rear crashes with WHIPS and AHR and to compare these data to those obtained with no head restraint (NHR).

METHODS

A Human Model of the Neck (Fig. 1A,B), consisting of a neck specimen mounted to the torso of BioRID II and carrying a surrogate head and stabilized with muscle force replication, was subjected to simulated rear crashes in a WHIPS seat (Fig. 1A; n=6, 12.0 g, ΔV 11.4 kph) or AHR seat (Fig. 1B) and subsequently with NHR (n=6: 11.0 g, ΔV 10.2 kph with AHR; 11.5 g, ΔV 10.7 kph with NHR). WHIPS consists of a fixed head restraint, yielding seatback, and a specialized recliner mechanism that contains deformable elements. The goals of WHIPS are to absorb occupant energy, minimize neck motions, and reduce forward rebound into the seatbelt. The AHR rotates forward via a pivoting mechanism between it and the seatback in attempt to contact the head immediately following the crash and minimize head and neck motions. Lower cervical spine facet and disc motions and ligament strains during the crashes were computed (Fig. 1C) and average peak values statistically compared (P<0.05) between WHIPS, AHR, and NHR.
RESULTS AND DISCUSSION

Average time-history responses for C6/7 intervertebral rotations, facet and disc translations, and ligament strains (Fig. 2) demonstrate temporal differences among WHIPS, AHR, and NHR. Average peak facet and disc translations and ligament strains could not be statistically differentiated between WHIPS and AHR or between AHR and NHR. WHIPS significantly reduced peak capsular ligament strain and peak disc separation at C6/7 as compared with NHR. Facet compression at C6/7 reached 2.9 mm with WHIPS, 1.9 mm with AHR, and 3.2 mm with NHR. Facet joint compression injury may lead to neck pain in some whiplash patients. Our results are supported by a previous in vivo simulated rear crash study in which the C5/6 instantaneous center of rotation shifted upward during the crash implying that the facets may forcefully collide leading to impingement injury of the synovial fold or articular cartilage.

CONCLUSIONS

- We determined the facet joint and disc kinematics and ligament strains of the lower cervical spine during simulated rear crashes with WHIPS, AHR, and NHR. These data could not be statistically differentiated between WHIPS and AHR or between AHR and NHR. WHIPS significantly reduced peak capsular ligament strain (5.3 vs. 32.8%) and peak axial disc separation (1.8 vs. 5.0 mm) at C6/7 as compared with NHR.
- WHIPS and AHR marginally reduced peak ALL strain as compared to NHR.
- Average peak facet joint compression reached 2.9 mm with WHIPS, 1.9 mm with AHR, and 3.2 mm with NHR.
- WHIPS and AHR effectively limited peak capsular strain below the subfailure threshold but did not protect against potential facet joint compression injuries which may occur during or following contact of the head with the head restraint.
- Future active neck injury prevention systems may be designed to reduce facet joint compression during rear crashes leading to reduced neck pain in whiplash patients.

Figure 2: Average C6/7 time-history responses during rear crashes with WHIPS, AHR, and NHR: A) intervertebral rotations (+R flexion, -R extension); B) facet translations; C) strains in the anterior longitudinal (ALL), posterior longitudinal (PLL), and anterior capsular (CL-A) and posterior capsular (CL-P) ligaments; and D) disc translations. Facet and disc translations are expressed in the facet and endplate coordinate systems, respectively, of Fig. 1C: +Tz anterior and -Tz posterior sliding (facet) or shear (disc); +Ty separation, -Ty compression; F front and R rear facet/endplate. Shaded regions representing ±1 standard deviation are shown only for rotation and Tz. Vertical lines represent the average duration of contact of the head with the HR. Panel C includes shaded regions representing the ALL failure strain threshold of 42.6% and the CL subfailure threshold of 35%.

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