DISCUSSANT COMMENTS ON "KINEMATIC AND SPINAL COLUMN INJURIES IN ACTIVE AND PASSIVE PROTECTION: RESULTS OF SIMULATED FRONTAL COLLISIONS" by D. Kallieris, R. Mattern, Gg.Schmidt and D. Warth, University of Heidelberg

David C. Viano and Thomas E. Anderson
Biomedical Science Department
General Motors Research Laboratories
Warren, MI 48090-9058

The authors are to be complimented for careful experiments and indepth analysis of kinematic variables associated with spinal column injury with lap-shoulder belt or airbag and kneebar restraint. All too often tests are completed and only a minimal analysis is performed correlating the biomechanical responses and anatomical injuries. This type of study provides an excellent opportunity to apply a multivariate analysis, as used by Eppinger (1), to separate the underlying influences of kinematics, specimen age (2), and seating height on cervico-thoracic injury.

The type of injury sustained by the neck depended on the restraint system used. The lap-shoulder belt system resulted in distraction-flexion type bony injuries predominately between the first and fourth thoracic vertebrae. Combined disc, ligament and bony injury occurred throughout the cervical spine, with disc injuries most common. The combined injuries to skeletal and soft tissue suggest possible spinal cord injury from vertebral instabilities (10,17). Cadavers restrained by airbag and kneebar sustained distraction-extension type injury at the cervico-thoracic junction and relatively few bony injuries in the upper cervical spine. These injuries differ from those observed by Cheng et al (3) with chest loading by a preinflated airbag which caused avulsion injuries of the odontoid process, and atlanto-occipital separations with ring fractures. They also found that head kinematics differed between belt and airbag restraint.

When the number of spinal column injuries is normalized by the number of tests performed with each restraint system, the pattern and frequency of cervico-thoracic injury are comparable, and the normalized histograms for the regional spinal AIS overlap, as the authors point out (however the head trajectory showed a more abrupt turn-around with the airbag system). One unresolved issue is when the cervico-thoracic injuries are occurring. The greatest forces on the neck occur when the head is in maximum flexion or extension, and this may occur in the transition from 2D to 3D head and neck kinematics.

The assumption that spinal column injury may be predicted by the maximum rotational acceleration and velocity of the head has some merit since the forces on the neck are proportional to the translational and rotational head accelerations in the absence of head contact. At any flexion-extension configuration of the head, the shear, bending and compressive forces on the neck are the significant factors that predispose for injury. However, the proper correlation of head accelerations and neck loads has yet to be established.

One interesting question relates to the clinical relevance of the cervico-thoracic spinal injuries observed with the two restraint systems. This study has emphasized the anatomical cervical injuries; however, the clinical significance of cervical injuries is reflected in the functional outcome related to spinal cord injury. Dislocation injury or intrusion into the spinal cord space has the potential for damage to the spinal cord with ultimate functional injury such as quadriplegia.

The inadequacy of classification of spinal injury as either flexion or extension (anteflexion or retroflexion in Kallieris' paper) is clear when the complex biomechanics of 3D neck loading and injury are considered. The authors correctly note that a 3D kinematic analysis is needed for a better assessment of the etiology of cervico-thoracic injury. Perhaps the application of multiple cameras and appropriate targeting of anatomical landmarks would allow 3D kinematic analysis.

A better description of the etiology of spinal column injury is possible if the system introduced by Roaf (14) and later refined by Panjabi, White and Brand (15) is used. This system describes the major and minor injury vectors responsible for the injury and permits comparison of injuries on a biomechanical basis. Although no quantitative evaluation of vector forces is involved, qualitative comparisons enable conclusions to be drawn regarding mechanisms of injury. The system provides greater detail than possible with the simple classification of flexion or extension motion.

White and Panjabi (16,17) have proposed a three-dimensional coordinate system, whose origin lies at the centrum of the upper vertebral body at an injury site. The load applied to a two-vertebra motion segment can be described as a combination of forces along and rotations about the three axes depicted in Figure 1. The applied forces and moments cause translation and rotation about the axes, and may ultimately lead to failure of bone, ligament or disc. A biomechanical analysis of regional spinal injury enables determination of the direction of loads and displacements leading to failure, and qualitative assignment of a Major Injury Vector (MIV) illustrating the combined force and moment responsible for failure.

With regard to injury classification, Allen (4) proposed a broad scheme for classifying the major injury forces associated with spinal injury. He found that distraction-extension injury, as observed with the airbag restraint system, may lead to neurological dysfunction in older individuals, but total cord lesions were uncommon (4). Distraction-extension motion accounts for 5% of the injuries in his series. By contrast, distraction-flexion injuries accounted for 37% and carried a high probability of serious spinal cord injury. Hyperextension injuries to the spine may cause spinal cord injury either by anterior compression due to disc extrusion or by posterior compression due to bulging of the ligamentum flavum (5-7). The frequency of hyperextension spinal injury is about equal to that of flexion injury (8), although the frequency is diminished if only injuries with neurological impairment are included (4, 9-11). Spontaneous reduction of vertebral dislocation injury has been noted in both flexion and extension injury (12,13) with a possible role of neck rotation emphasized by Roaf (13). The instability of combined bone-ligament injury, such as occurring with flexion teardrop, fracture-dislocation suggests that an evaluation of anatomical injuries be made by x-ray prior to movement of the test subject (10).

Allen (4) found that his mechanistic classification for cervical spinal injury, based on clinical data, indicated a different probability of neurologic lesion associated with each distinct injury modality. It is possible to define Allen's categories in terms of the local coordinate system and Major Injury Vector, as shown in Figure 2. The injuries represent the major categories of fractures and dislocations with a spectrum of anatomic damage within each category. There are two advantages of this classification scheme. First, it provides a precise biomechanical description of the spinal injury, based on the injury vector at the vertebral level rather than simply the motion of the head relative to the torso. This allows comparison of data between laboratories, and provides additional insight into injury mechanisms. Second, by comparison with the clinical data it is possible to infer a probability for associated neurologic lesion, which represents the critical aspect of a cervical spine injury. Much work remains to further validate these probabilities, but this classification represents a helpful step toward the correlation of vertebral and neurologic injury.

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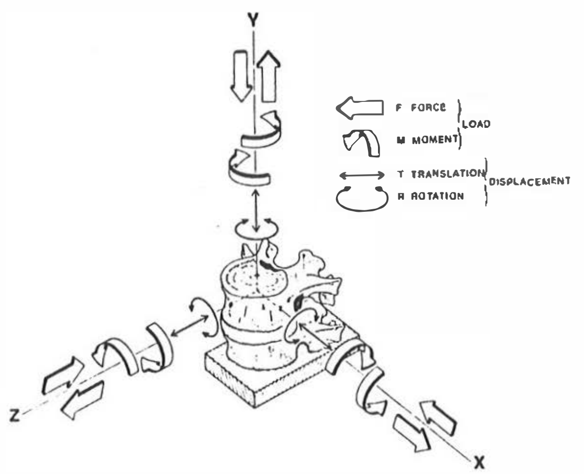
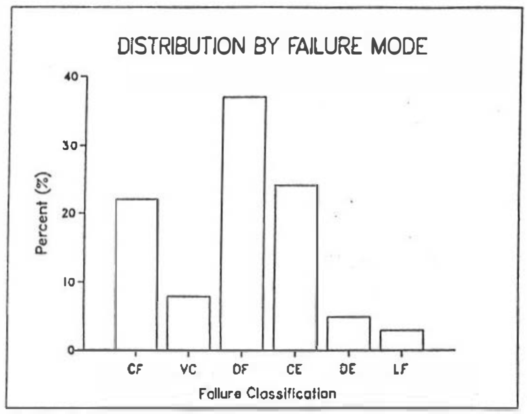


Figure 1: Injury biomechanics description for spinal column damage. From White and Panjabi (17).



CF =	Compressive Flexion	-y Force, +x rotation
VC =	Vertical Compression	-y force
DF =	Distractive Flexion	+y force, +x rotation
CE =	Compressive Extension	-y force, -x rotation
DE =	Distractive Extension	+y force, -x rotation
LF =	Lateral Flexion	Z rotation

Figure 2: Distribution of cervical spine injuries according to the classification scheme of White and Panjabi. Adapted from Allen (4).