CERVICAL SPINE INJURIES IN MOTOR VEHICLE CRASHES

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OVERVIEW

Safety systems advances have had a profound effect in reducing injury in motor vehicle accidents. Automotive safety advances offering protection to the neck currently include seatbelts, airbags, and head rests. Seatbelts were designed to prevent occupants from being ejected, historically a frequent cause of neck injury. Seatbelts and airbags were also designed to protect the head, face and neck from contact with the vehicle interior. Head rests are intended to support the head and prevent hyperextension in rear impacts. The airbag has been proposed to offer protection against hyperflexion in frontal impacts, but its ability to limit cervical motion has not been proven.

Despite gains in protection, crashes in late model vehicles may still result in injury to the cervical spine. Motor vehicle accidents are currently the most common cause of injury to the cervical spine (National Spinal Cord Injury Data), resulting in chronic pain, paralysis and death. The cervical spine functions to protect the spinal cord while allowing movement of the head. Structurally, complex motion of the head is provided by seven cervical vertebrae, each offering relative motion. Excessive motion, though, may result in bony or soft tissue damage to the cervical spine and may compromise its ability to protect the spinal cord. Injurious motion of the head may result from the dramatic accelerations or decelerations that occur in motor vehicle accidents. In addition, contact of the head with interior components of the vehicle may apply additional compressive, tensile or bending forces to the neck.

Multiple mechanisms of injury to the cervical spine have been defined. These include excessive flexion, extension or lateral rotation that may be combined with compression or tension (Allan 1982). The specific anatomical structure and location of injury that the cervical spine sustains is dependent in the mechanism of injury applied. It is also sensitive to the initial position of the head relative to the neck, the rate of loading and the degree to which the neck is constrained also affect the tolerance. Individual parameters, including the presence of preexisting pathology or deformities, as well as the geometry and bone density, also effect biomechanics. Pediatric cervical spines behave differently from adult on due to anatomic features including proportionately heavier heads as well as material differences including greater ligament laxity and growth centers that are susceptible to shear forces (Orenstein 1984).

In addition to the biomechanical complexities of the cervical spine, there are a myriad of occupant kinematics that can result from motor vehicle accidents. Injury can occur when the head moves relative to the torso with either sufficient rotation to exceed the normal range of motion or with sufficient force to load the cervical spine beyond its tolerances. In frontal crashes, the restraint system acts to rapidly decelerates the torso, while the head remains in motion until it reaches its end of range of motion in flexion.

Injury may occur even without contacting the vehicle interior from this forced spinal rotation (Huelke 1993). In rear impacts, the torso may be accelerated forward by the seatback, potentially resulting in relative rearward motion of the head, and subsequent potential for injury. Similarly, side impacts accelerate the restrained torso causing relative lateral motion of the head. Additional external loading may result from head contacts to the steering wheel, dashboard or other interior components. Contact injury scenarios include direct loading of the seatbelt against the neck (Lynch 1996), and interaction with a deploying airbag.

To assess the details of specific crash scenarios resulting in cervical spine injury, the Crash Injury Research Engineering Network (CIREN) has gathered data on motor vehicle accidents occurring in late model vehicles (1990 model year and newer). In-depth focus by a multi-disciplanary team is given to both clinical and mechanical aspects. Informed hypotheses can then be generated as to the occupant kinematics and precise mechanism of injury. This current study focuses on occupants who are using the available safety restraints or have an airbag deploy. A spectrum of crash impact types were observed to result in a variety of injury mechanisms and cervical spine injuries. Cases are presented in order by the principal direction of force (PDOF) applied to the subject vehicle, beginning at lateral impact to the driver’s side (9 o’clock) and continuing clockwise to frontal impact then to right side lateral impact.

CASE REPORTS

9 o’clock

A 1996 Mercedes C-220 was impacted on the left side by a 1997 Ford pick-up truck. The change in velocity over the crash pulse (delta V) for the Mercedes was approximately 24 mph with a principal direction of force (PDOF) of approximately -80 degrees. The 27 year old female driver (5’2”, 180 lb) was restrained with a lap/shoulder harness and had an airbag deploy. She sustained a subdural hematoma, transsected aorta, multiple rib fractures, a C2-C3 transsection of the spinal cord and fractures/dislocations of the C1-C5 posterior vertebral bodies. She did not survive. The hypothesized mechanism for cervical spine and spinal cord injuries is contact of the head to the A-pillar and roof rail followed by violent lateral neck flexion to the right.

11 o’clock

A 1991 Mazda Miata was impacted at the left front corner by a 1993 Chevrolet full-size sedan. The delta V for the Miata was approximately 8 mph with a PDOF of between -45 and -15 degrees. The 45 year old female driver (5’4”, 112 lb) was restrained with a lap/shoulder harness and had an airbag deploy. She sustained a fracture of the anterior axis and transverse process of the axis. She also had multiple brain hemorrhages and contusions. The subject was found at the scene in full cardiac arrest. The hypothesized mechanism for her cervical spine injuries is hyperextension with distraction, which may have occurred due to interaction with the airbag. A long crash pulse was suggested by a head contact to the windshield that may have occurred in advance of the airbag deployment. Damage to the left front of the vehicle was narrow and may have delayed reaching critical deceleration to deploy the airbag. This additional time would allow the subject to be out of position at the moment of deployment.

11 o'clock
A 1992 Honda Civic was impacted on the left front by a 1988 Toyota compact car. The delta V for the Civic was approximately 17 mph with a PDOF of between -45 and -15 degrees. The 27 year old male driver (6'2", 215 lb) was unrestrained but had an airbag deploy. He sustained a posterior C4-C5 lamina fracture with anterior subluxation and 50% canal stenosis. The hypothesized mechanism for cervical spine injuries is hyperextension. Hyperextension created compressive forces posteriorly in the cervical spine sufficient to fracture of the lamina. Injury may have occurred due to interaction with the airbag because the subject was unbelted and moved out of position forward and to the left due to the PDOF of 11 o'clock.

12 o'clock
A 1995 Saturn SL-2 was involved in a head-on collision with a 1984 Oldsmobile full-size sedan. The delta V for the Saturn was approximately 13 mph with a principal direction of force (PDOF) of between -15 and 15 degrees. A 2 year old male front passenger (2'8", 21 lb) was unrestrained on the lap of an unrestrained occupant. The airbag deployed in the crash. The child sustained fracture and dislocation of the posterior atlas and posterior axis with transsection of the spinal cord. Abrasions to the chin, neck, lip and scalp were also noted. The hypothesized mechanism for cervical spine injuries is contact to the head causing hyperextension of the head and shear across the cervical spine. These kinematics are consistent with interaction with a deploying airbag.

12 o'clock
A 1992 Ford Tempo was involved in a head-on collision with a tree. The delta V for the Tempo was approximately 27 mph with a PDOF of between -15 and 15 degrees. The 38 year old female driver (5'6", 145 lb) was restrained with a lap/shoulder harness. She sustained fractures of the spinous processes of C6 through T1 and a left frontal brain contusion. Contusions of the eye, nose and left breast were also noted. There was also a neck laceration, possibly due to interaction with the shoulder restraint. The hypothesized mechanism for cervical spine injuries is hyperextension with compression. There is injury and contact evidence that the subject's face hit the steering wheel as the upper body moved forward upon vehicle deceleration. The head would then likely be forced into extension, loading the posterior cervical spine in compression and resulting in the documented fractures.

12 o'clock
A 1992 Ford Escort was involved in a head-on collision with a 1992 Acura mid-size car. The delta V for the Escort was approximately 21 mph with a PDOF of -10 degrees. The 36 year old female driver (5'7", 125 lb) was restrained with a lap/shoulder harness. She sustained C5 and C6 spinous process fractures, C6-C7 facet mal-alignment, a left clavicle fracture and hemothorax with a right 7th rib fracture. There were no injuries or external marks above shoulder level. There were also no visible occupant contact marks within

the vehicle. Cervical spine injuries are hypothesized to be the result of rapid vehicle and restrained torso deceleration with the continued motion of the driver's head. The head was forced into hyperflexion passed its normal range of motion, overloading the posterior ligaments of the neck in tension. Sufficient tension in ligaments at the spinous processes can cause the bony fracture if the ligaments are stronger than the local bone.

1 o'clock

A 1991 Toyota Tercel broadsided the left side of a 1993 Ford compact car in an intersection. The delta V for the Tercel was 15 mph with a PDOF of 30 degrees. The 83 year old female driver (5' 2", 120 lb) was restrained with a shoulder harness only. She sustained fractures of the C2 vertebral body and C6 spinous process, as well as contusions to the face, thorax and lower extremities. The subject had a history of severe osteoporosis and hypertension. Only knee contacts were noted in the vehicle. Forced rotation of the head into flexion combined with poor bone strength are hypothesized to have resulted in these non-contact injuries of the cervical spine.

2 o'clock

A 1996 Toyota Camry was t-boned on the right side by a 1983 Oldsmobile full-size sedan. Damage of to the Camry was to the front right corner. The delta V was 15 mph with a principal direction of force of 45 degrees. The 51 year old female (5'0", 115 lb) front passenger was restrained by a lap/shoulder harness and a passenger side airbag was deployed. She was sustained a C6 spinous process fracture and a C6-C7 burst fracture without neurological deficit. A contact was noted at the sunvisor of the passenger side. Burst fracture is the result of compressive load applied rapidly to the vertebral body. This loading can occur with impact to the top of the head directed along the neck. The hypothesized mechanism for injury was therefore head contact to the sunvisor. The spinous fracture may have occurred with either forced extension or flexion upon interior contact.

2 o'clock

A 1994 Toyota Tercel was t-boned on the right side by a 1981 Ford van. The delta V for the Tercel was approximately 23 mph with a principal direction of force (PDOF) of between 45 and 75 degrees. The 45 year old female driver (5'3", 184 lb) was unrestrained but an airbag deployed in the crash. She sustained fracture of the atlas at the anterior transverse foramen and a subarachnoid hemorrhage. Interior occupant contact was noted at the right side A-pillar. This unbelted occupant was thrown toward opposite of the principal direction of force and hit her head at this contact point, despite the presence of a deploying airbag. The hypothesized mechanism for her cervical spine injury is direct impact to the head causing compression to the neck and possibly hyperflexion.

3 o'clock

A Ford Escort/Pony was broadsided on the right side, rear of the B-pillar, by a 1991 GMC pick-up. The delta V for the Escort was approximately 31 mph with a PDOF of approximately 80 degrees. The 36 year old pregnant (6 months) female front passenger

(5' 3", 171 lb) was restrained with a lap/shoulder harness. She sustained a fatal odontoid fracture with transsected spinal chord and an uncal herniation. Abrasions to the neck, chest and upper extremity were also sustained. The subject was found by medics with her neck wrapped about shoulder harness. The shoulder belt is hypothesized to have resulted in the fatal cervical spine and subsequent spinal cord injury by direct loading of the neck and possibly forced extension.

4 o'clock
A 1991 Chevrolet Corvette was t-boned on the right side by a 1997 Plymouth minivan. The delta V for the Corvette was approximately 48 mph with a PDOF of 120 degrees. The 51 year old male driver (6'3", 245 lb) was restrained with a lap/shoulder harness. He sustained ligamentous disruption at C4-C5 with disc herniation which resulted in C5 level tetraplegia. The hypothesized mechanism for this cervical spine is lateral flexion of the head toward the direction of impact with the minivan. Because impact was also from a slightly rearward direction, the subject loaded the seatback, with the head extending and possibly rotating clockwise. Recoil from the seatback may have also resulted in flexion of the head forward. Complex head motion was sufficient to force the cervical spine out of its normal range of motion, loading ligaments to failure and destabilizing the spine. The spinal cord was then unprotected from injury by subsequent motion of the head.

DISCUSSION

Based on documentation and analyses of late model motor vehicle crashes resulting in cervical spine injury, a plan can be developed for injury prevention through safety engineering. The first step is to look to an understanding of the properties of the cervical spine. "Intelligent design of safety features in vehicles for protection of occupants is necessarily based on knowledge and understanding of human biodynamic response to impact (King)". A knowledge base has been built through cadaveric and volunteer testing, animal models, mathematical simulations, use of anthropometric dummies and actual case data. Cadaveric and volunteer testing has provided neck tolerance values for humans exposed to the decelerations of simulated crashes, as well as direct impact to the head. These levels of force and acceleration can be assessed by anthropometric dummies in actual crashes as measure of vehicle performance to protect against neck injury.

Actual case data, with the focus of the information presented here, has great utility in the development of testable hypotheses for the behavior of the human cervical spine during a crash in an automobile. These can include such example study questions as:

Are airbags protective to cervical spine flexion in frontal impacts?

Can seatbelts be designed to shape the occupant deceleration pulse and reduce impulse?

Can rigid seatbacks reduce injury by reducing recoil?

Does head rotation affect the severity of cervical spine injury in lateral impacts?

Developing and answering questions such as these is essential in implementing successful safety design improvements.

In summary, a flow of information can be presented. Initially, there is the documentation of cervical spine injury in motor vehicle accidents. To begin to alleviate this problem, we look to science and engineering to gain knowledge into the biodynamics of the human cervical spine. Based on tolerance data, a surrogate dummy allows safety testing of vehicles involved in crashes. Improvement in design can then be developed and assessed. If cervical spine injuries persist, the loop will continue with the arrival of new patients to our trauma centers despite use of most modern optimal safety devices. The neck is a vulnerable anatomical site as long as the head is not directly coupled to the torso. Motion of the unrestrained head will therefore continue to result in neck injury. It is the goal of the auto manufacturers and health care institution alike to implement new safety approaches directed at breaking this cycle and the prevention of injury.