Cervical injuries suffered in automobile crashes

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The National Crash Severity Study data in which occupants sustained severe, serious, critical-to-life, or fatal cervical injuries were reviewed. Of passenger cars damaged severely enough to be towed from the scene, it is estimated that one in 300 occupants sustained a neck injury of a severe nature. The neck-injury rate rose to one in 14 occupants for those ejected from their cars, although many of these injuries resulted from contacts within the car before or during the process of ejection. Severe neck injuries were rather rare in cars struck in the rear, but were more common in frontal and side impacts. Occupants between 16 and 25 years of age had such injuries more than twice as often as those in any other age group. Most of the neck injuries of a more severe nature involved the cervical spine or spinal cord. Injuries of the anterior aspect of the neck were relatively infrequent, and usually resulted from direct blunt impacts. National projections of the number of fatalities related to cervical injuries indicates that 5940 deaths, or approximately 20% of all in-car deaths, include fatal cervical spine injuries, and that about 500 cases of quadriplegia per year result from automobile accidents.

KEY WORDS • cervical spine injury • seat belts • motor-vehicle accident • quadriplegia • spinal cord injury

Cervical injuries of a severe nature related to automobile crashes are well known to the attending clinician. However, the frequency of such injuries has not been adequately documented, because a reliable data base heretofore has not been available. Recently, the National Highway Traffic Safety Administration (NHTSA) established a National Crash Severity Study (NCSS) of statistically sampled automobile crashes in the United States, providing detailed information on passenger cars and their occupants in tow-away crashes. The information available includes pertinent vehicle and environmental details as well as the location, types, and severity of injuries to the occupants.

This report will provide an insight into the causes of the more severe cervical injuries sustained by occupants of crashed automobiles.

Literature Review

A report from Germany on an extensive series of car crash injuries indicates that severe to fatal cervical spine injuries occur in 0.4% each for drivers and for passengers. This report indicates that more than 50% of all cervical spine injuries were in rear-end crashes, but that the highest risk of severe and fatal cervical injuries is incurred in front-end crashes. From autopsies conducted in Australia, Tonge, et al., found cervical fractures or dislocations in 11% of drivers and in 17% of passengers. Another report from Australia, of 500 driver and passenger autopsies, indicates that 7% had cervical fractures with cord damage. In the United States, Alker, et al., found that 21% of 146 consecutive traffic accident autopsies showed radiographic evidence of cervical spine injuries. However, these cases included pedestrians, where cervical spine injury is not an infrequent finding. When autopsy findings and cervical spine x-ray films were studied together, Bucholz, et al., reported that of 100 fatally injured motor-vehicle crash victims, 24% had cervical fractures or fracture-dislocations. They indicated that neither gross inspection nor radiography alone will uncover all occult cervical lesions.

Although there have been a few articles on laryngeal trauma in the clinical literature, there are no data on the frequency of injuries to the anterior portion of the neck (throat) structures. Most data on laryngeal injuries are clinical case reviews,
Cervical injuries in automobile crashes

with most authors agreeing that such injuries are due to blunt trauma to the throat from impact to the steering wheel rim or to the upper instrument panel. Tonge, et al.\textsuperscript{9} reported an injury incidence of 9\% to anterior throat structures in autopsied car drivers and passengers, most (65\%) having died of head and/or chest injuries. Specific types of throat injuries and their severity were not indicated.

**Data Source**

Up to the present time, the frequency of the more severe neck injuries or fatalities in passenger car crashes has not been estimated from a vehicle accident population, although frequency estimates of spinal cord injuries have been made from clinical surveys. Recently, a large set of automobile crash injury reports have become available for analysis. This, the NCSS, is a major accident data collection program of the National Center for Statistics and Analysis of the NHTSA. Available in this data bank are detailed crash configuration information, descriptions of injuries and their sources (contact points), and a quantitative description of vehicle damage. Crashes in this study were selected on a strictly stratified sampling plan, and have some potential for making projections to a national population.

In the NCSS program, the detailed accident injury data were collected from investigations conducted by professional teams operating in eight regions of the United States. During the period from January, 1977, through March, 1978, 6628 accidents were investigated, and the pertinent data were computerized. In these accidents, there were 8616 tow-away passenger cars containing 14,491 occupants. For 10,151 of these occupants, detailed injury information was available from qualified medical sources.

**Injury Classification**

The Abbreviated Injury Scale (AIS) is used in the NCSS file to categorize the severity of injury. This scale is used extensively in research on automobile crash injuries and has been extended to other areas as well.\textsuperscript{3,28} The AIS categorizes injuries by severity: minor (AIS-1), moderate (AIS-2), severe (AIS-3), critical-to-life (AIS-5), and fatal (AIS-6).

The following is a list of diagnoses of the more severe (AIS-3,4,5) or fatal neck injuries:  

- AIS-3: Fracture and/or dislocation (C-4 or below) with or without nerve root damage; fracture of the transverse or spinous process; laceration involving nerves and/or blood vessels; tracheal crush
- AIS-4: Esophageal obstruction; fracture or laceration of the larynx; laceration with severe hemorrhage; tracheal laceration
- AIS-5: Fracture and/or dislocation (C-4 or below) involving cord damage; avulsion or laceration of the esophagus; avulsion of the larynx; laryngeal injury with serious respiratory difficulty; pharyngeal obstruction; avulsion of the trachea
- AIS-6 (Fatal): Cervical spine crush or laceration (C-3 or above); fracture and/or dislocations (C-3 or above) with cord damage.

In the AIS system, the outcome (sequela) of injuries is intentionally not coded; yet quadriplegia or quadriparesis, as reported in other studies, would most likely be at the AIS-5 level of severity.

**Data Analysis**

**Overview**

As indicated previously, detailed injury information was available from qualified medical sources for 10,151 occupants in tow-away passenger-car crashes, and this information is the basis for most of the analysis in the discussion of this paper.

Autopsy reports were not available for about half of the fatally injured occupants; it is likely that many of these sustained severe neck injuries which would have added to the total counts. On the other hand, there are apparently few missing data for persons with severe neck injuries who survived. The accidents were sampled in such a way that the total population can be reconstructed from the sample. For the 16-month period considered here, the total estimated occupant population (that is, the number of occupants of passenger cars towed for crash damage within the NCSS sites) is 62,026. Most of the frequencies given in this report will be based on the reconstructed population; for some of the discussions of injury detail, data will be presented only for those persons who had medical reports of their injuries, and these will be given in raw or unweighted form.

**Frequency of Severe Injury**

The incidence of the more severe (AIS-3,4,5) or fatal (AIS-6) neck injuries is low. Of the 10,151 actual occupants with detailed medical information, 131 had neck injuries. Of these 131 occupants, 63 were killed, the majority (53) after sustaining a fatal neck injury. The reconstructed number of neck-injured persons is 145 (see discussion of reconstruction techniques\textsuperscript{16}). The field notes for fatal accident cases for which full medical reports were not available have been studied in detail by us. As a result of this review, 64 additional persons were judged to have sustained severe to fatal neck injuries (most of these being fatal). Therefore, of the 62,026 occupants of passenger cars in tow-away crashes, 209 (or one person in 300) were estimated to have sustained neck injury of AIS-3 to AIS-6 severity.

The distribution of the AIS level for neck injuries and for degree of ejection from the car is shown in Table 1. Of the 209 occupants with the more serious neck injuries (AIS-3 to AIS-6), 67\% were not ejected from the car. Of these occupants not ejected, only
0.2% had the more serious or fatal neck injury compared to some 7.2% of those ejected, a frequency 36 times greater.

When these more serious or fatal neck injuries were compared with the worst injuries elsewhere in the body, it was found that the neck was the most seriously injured body area in 62% of these occupants. Although no specific age group is immune from the more serious neck injuries in passenger car crashes (Table 2), it appears that neck injuries are the "mechanized disease" of the young adult. Car occupants between 16 and 25 years of age sustain severe to fatal neck injuries four times as often (0.43%) as those younger than 16 years (0.12%) and twice as often as those older than 25 years (0.23%). In general, occupants in the age range of 16 to 25 years are involved in more serious crashes than are either younger or older persons. One measure of this phenomenon available in the NCSS data is the average value of Delta-V, the instantaneous change in velocity of the car, recorded for the vehicles at the time of the crash. For all 16- to 25-year-old occupants, the average Delta-V was 16.4 mph, as compared with 14.7 mph for younger occupants, and 14.4 mph for those older than 25 years. One may infer that the "age" effect noted above (that is, a higher frequency of severe and greater neck injuries to 16- to 25-year-olds) is really the result of more severe crashes than an anatomical susceptibility to injury.

The type of crash is clearly related to the occurrence of the more severe neck injuries. Table 3 illustrates the crash type in the reconstructed population. More occupants sustain severe neck injuries in frontal or side impacts, but the rate of such injuries is higher in rollovers than in any other type of crash. Such injuries are relatively rare in rear-impacted passenger cars.

The type of neck injury is clearly related to the type of crash. Table 3 illustrates the crash type in the reconstructed population. More occupants sustain severe neck injuries in frontal or side impacts, but the rate of such injuries is higher in rollovers than in any other type of crash. Such injuries are relatively rare in rear-impacted passenger cars.

Type and Location of Neck Injuries

A review of the more severe neck injuries and neck-injury-producing fatalities among the 130 car occupants with medical reports indicates that the majority of these injuries are located in the posterior aspect of the cervical region, that is, the cervical spine and spinal cord. Of the 131 more severe injuries listed for the 130 car occupants, fractures were the most frequent cervical injury reported (76%, or 100 injuries), and 53 injuries (40%), all in the cervical spine, led to death. Eight individuals had injuries classified as AIS-3 or AIS-4 in the anterior aspect of the neck, most of which involved throat structures, including fractures or transection of the larynx or trachea, or lacerations of the neck involving major blood vessels or their branches.

Contact Sites Related to Neck Injuries

The original investigator's written reports of all the severe, serious, or fatal neck-injury cases were individually reviewed, specifically to identify the contact areas. Not infrequently, the contact was indicated as "hyperextension." Review of these reports indicated that most of these "hyperextension" cases actually involved head contact with the windshield or other in-car structures. Therefore, the contact points more clearly defined the objects struck (Table 4).
Cervical injuries in automobile crashes

### TABLE 4

Cervical injury and contact points for occupants not ejected from the car

<table>
<thead>
<tr>
<th>Contact Points Related to Injury</th>
<th>Fracture-Dislocation</th>
<th>Fracture</th>
<th>Anterior Neck*</th>
<th>Dislocation</th>
<th>Total Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>windshield</td>
<td>7</td>
<td>16</td>
<td>3</td>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td>door area</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>roof</td>
<td>1</td>
<td>7</td>
<td></td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>A-pillar†</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>steering wheel</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>other‡</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>side window &amp; or frame</td>
<td>1</td>
<td>3</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>seat back</td>
<td>2</td>
<td>2</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>instrument panel</td>
<td>1</td>
<td>2†</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>rear view mirror</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>side roof rail</td>
<td>1</td>
<td>2</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>intruding object</td>
<td>1</td>
<td></td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>unknown</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Includes deep lacerations of the anterior neck structures, of the carotid artery and/or major branches, fracture or transection of the larynx, or cricoid cartilages, and tracheal transection.
†Includes one case of cervical fracture (C-2) and fracture of the thyroid cartilage.
‡The A-pillar is the roof support at the side of the windshield.
§Includes the headrest, heater and air conditioning ducts, glove compartment, sun visor, and intruding hood.

Rarely, if at all, is the neck fractured or dislocated by direct impact to the cervical area. However, the anterior neck structures are almost always injured by direct blunt impacts or impacts causing deep lacerations (Table 4).

For those not ejected from the car, the more serious or fatal neck injuries are more often associated with windshield contact. Approximately one-third of the car occupants with such neck injuries had head-windshield contact. Less often, such injuries are sustained from striking the roof, door, A-pillar, or steering wheel (Table 5). Other car structures are contacted even less frequently. Occupants who were "ejected" or "partially ejected," had the majority of the neck-injury-producing contacts on interior vehicle structures.

**Restraint System Effectiveness**

Almost all of the more serious or fatal neck injuries were sustained by occupants who were not wearing seat belts (Table 6). Of the 130 car occupants with the more severe or fatal neck injuries, and with full medical data, only four suffered the more serious neck injuries or a fatal cervical lesion when wearing a lap or lap-shoulder belt. All were in very severe crashes.

The effectiveness of lap-shoulder belts in reducing the frequency and severity of injuries have been previously reported.16,17 These reports indicated that the more serious or fatal neck injuries are not found in front-seat occupants who were wearing lap-shoulder belts.

**National Projections**

The NCSS data were obtained from stratified random samples of towed passenger cars in eight relatively small regions of the United States. The eight regions were chosen so as to reasonably represent the rural/urban distribution of the nation, and it seems appropriate to attempt national projections of some of the observations. Details of the techniques used for this projection have been presented elsewhere.15,18

From the national projections, it seems likely that approximately 6000 passenger-car occupants per year die principally as a result of a broken neck. Ap-

### TABLE 5

Contact areas producing severe to fatal cervical injuries*

<table>
<thead>
<tr>
<th>Contact Area</th>
<th>Occupants Not Ejected</th>
<th>Occupants Ejected</th>
</tr>
</thead>
<tbody>
<tr>
<td>windshield</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>roof†</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>door area</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>A-pillar‡</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>steering wheel</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>instrument panel</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>side window or frame</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>seat back</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>rear view mirror</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>exterior or intruding object</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>hood</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>headrest</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>heater/air conditioning duct</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>unknown</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>B-pillar§</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ground</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>95</td>
<td>25</td>
</tr>
</tbody>
</table>

*Ten cases "unknown if ejected" are not listed.
† "Roof" includes the inside of the roof of the car (11 cases), the side roof rail above the door opening (four cases), and the sun visor or front of roof over the windshield (two cases).
‡ The A-pillar is the vertical side windshield and roof support.
§ The B-pillar is the vertical support to which the front door latches and to which the hinges of the rear door attach.
Biomechanics of Neck Injuries

Cervical Spine Injuries

The more serious or fatal injuries of the cervical spine are fractures or fracture-dislocations, with or without spinal cord involvement. The medical literature has provided a good description of the kinds of injuries seen from clinical experience. There are a variety of cervical fractures and fracture-dislocations, each having its own specific mechanism of injury. Over-bending fractures (hyperflexion: forward bending, or hyperextension: backward bending) each may be one of two types associated with compression factors, that is, hyperflexion or hyperextension with compression or with tensile forces (distraction hyperflexion or hyperextension). In addition, there may be rotational forces involved with each of the above types of injury. Lateral bending fractures are another type, producing compression of vertebral structures on the side of the bending and tensile forces, possibly separating similar structures on the opposite side. At the upper cervical level (C-1 to C-2) specific fractures, different from those found lower down in the cervical area, are noted. In car crashes, neck fractures and/or dislocations are almost always the result of excessive forces transmitted through the cervical spine by the postcervical body mass (torso) when the head has decelerated on an interior car structure. In rollover crashes, for example, the "neck-roof contact" is really a head contact with neck-loading by the torso mass. However, as reported by Huelke, et al., neck fractures and fracture-dislocations may occur without head impact.

There are no frequency data for the various types of neck fractures or fracture-dislocations. No reports are available indicating direct impact to the neck causing cervical fractures in car crashes. The state of knowledge on the quantitative biomechanics of the forces required to cause neck fracture or dislocation of the cervical spine is very limited.

The only dynamic experimental study available at this time to determine cervical spine injury types in humans is on superior-inferior impact loading of the cervical spine through the head, as reported by Culver, et al. Impact tests on 11 cadavers were conducted with a moving mass impactor. Cervical fractures were produced in many cases without basilar skull fractures. The mechanism of cervical vertebral fractures in the test configuration used appeared to be the compressive arching of the neck, increasing the cervical lordotic curve, which places loads on the spinous processes, lamina, and facets. The work reported in this study was intended as a preliminary study, and much further work is needed to fully explore the various mechanisms of cervical vertebral damage found in superior-inferior loading cases.

The work of Mertz and Patrick has been the only study to date to suggest human tolerance values for the cervical spine loading due to indirect (inertial) loading. Based on results from human volunteers and cadaver sled tests, they found that the resultant bending movement about the condyles was an excellent indicator of neck strength. Although this work was done some years ago, there has been no subsequent work which has indicated larger tolerance values of the neck loading.

<table>
<thead>
<tr>
<th>Restraint System</th>
<th>No. Injury</th>
<th>AIS Level of Reported Neck Injury</th>
<th>Total Cases</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>No belts</td>
<td>7471</td>
<td>874</td>
<td>1133</td>
<td>1025</td>
</tr>
<tr>
<td>belts</td>
<td></td>
<td>22</td>
<td>25</td>
<td>53</td>
</tr>
<tr>
<td>Lap/shoulder</td>
<td>231</td>
<td>26</td>
<td>26</td>
<td>2</td>
</tr>
<tr>
<td>Lap only</td>
<td>223</td>
<td>24</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>Shoulder only</td>
<td>2</td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Passive</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Child seat</td>
<td>15</td>
<td></td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Unknown</td>
<td>1024</td>
<td>100</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>8968</td>
<td>1025</td>
<td>1015</td>
<td>3</td>
</tr>
</tbody>
</table>

TABLE 6

Neck-injured persons and restraint systems

Percent

Cases

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D. F. Huelke, J. O'Day and R. A. Mendelsohn
Cervical injuries in automobile crashes

**Throat Injuries**

The tolerance levels of throat structures are better known. In 1968, Nahum, et al. tested intact embalmed cadavers with loads of 200 to 250 lbs, producing marginal fractures of the thyroid cartilage. The cricoid cartilages fractured at loads of 175 to 225 lbs. In 1971, Gadd, et al. experimenting with cadavers, showed marginal fractures of the laryngeal cartilages at 90 to 100 lbs. It is believed that the stiffening of the embalmed tissue about the larynx was responsible for the lower loads required to produce fracture.

Most recently, Melvin, et al. studied the fracture load level of larynges removed from cadavers. For the thyroid cartilage, the mean dynamic fracture load was 40.6 lbs, and for the cricoid cartilage, 55.5 lbs, significantly lower than the figures in the 1968 and 1971 studies. The mean load for imminent structural collapse was found to be 100 lbs. No tolerance research studies have been conducted on penetration injuries of the neck.

**Conclusions**

Previous studies of highway-related cervical injuries have been based on clinical reviews, and not on a known automotive accident population. The NHTSA-sponsored National Crash Severity Study has provided for the first time an adequate sample of actual crashes so that cervical injury frequencies and severities can be estimated.

The NCSS data set used for this study represents a population of 62,026 occupants of passenger cars involved in tow-away accidents, and thus the frequencies quoted here apply to such a group. Of all such persons, one in 300 had a cervical lesion in the range of AIS-3 to AIS-5, or fatal. For persons who were not ejected from their cars, this rate was one in 433. For ejected occupants, the rate was one in 14. Yet many of those ejected contacted in-car structures, sustaining the cervical injury prior to, or in the process of, being ejected.

Although neck injuries of the more severe nature, or cervical fatalities, are relatively infrequent in car crashes, one in five of the fatalities in the NCSS data had a neck fracture of AIS-3 or greater. Few of those wearing seat belts were so injured. Since the majority of these neck fractures occurred in frontal or side crashes, it would be expected that lap-torso restraints would have markedly decreased the occurrence of the more severe neck injuries.

A comparison of the AIS-3 to AIS-5 level neck injuries with the worst non-neck injuries elsewhere in the body indicates that the neck was the more seriously injured body area for 62% of these occupants. More occupants sustain severe neck injuries in frontal or side impacts, but the rate of such injuries is higher in rollovers than in any other crash type. Such injuries are relatively rare in rear-impacted passenger cars.

Car occupants between 16 and 25 years of age sustain severe to fatal neck injuries four times as often as those younger than 16 years old, and twice as often as do those older than 25 years. Of the 131 more severe injuries listed for the 130 car occupants, 53 (40%) were cervical spine injuries resulting in death. There were eight individuals who had injuries categorized as AIS-3 or AIS-4 in the anterior aspect of the neck, most of which involved throat structures, including fractures or transection of the larynx or trachea, or lacerations of the neck involving major blood vessels or their branches.

Rarely, if at all, is the neck fractured or dislocated by direct impact to the cervical area. The anterior neck structures, however, are almost always injured by direct blunt impact or impact causing deep lacerations.

For those not ejected from the car, the more serious or fatal neck injuries are more often associated with windshield contact. This association should be viewed with caution, for in our own investigations, we have rarely noted serious or fatal neck injuries from windshield contact.

Contacts causing neck injury most often resulted from the movement of the unrestrained occupant into the car structure rather than invasion of the occupant space by extreme vehicle deformation. Review of the contact areas for occupants not ejected indicates that in many cases the objects related to the neck fracture would not have been contacted had adequate restraints been employed.

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