CERVICAL INJURIES IN AUTOMOBILE CRASHES

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16. Abstract

National Crash Severity Study cases in which occupants sustained cervical injuries in the range AIS-3 to AIS-6 were reviewed. Of a total reconstructed population of 62,026 occupants in passenger cars damaged severely enough to be towed from the scene, one in 300 sustained a neck injury of this severity.

The neck injury rate rose to one in fourteen 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 are rather rare in cars struck in the rear, but are more common in frontal and side impacts. Occupants between 16 and 25 years of age had such injuries more than twice as often as any other age group.

Anterior neck injuries of AIS-3 to AIS-6 severity were relatively infrequent, and usually resulted from direct blunt impacts.

Projections are made of the national number of fatalities (5,940) resulting from cervical fractures (approximately 20% of all in-car deaths), and of the number of quadraplegics resulting from automobile accidents (about 500 per year).

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I. INTRODUCTION

Relatively severe cervical injuries are of major concern because of the potential for permanent paralysis. Cervical trauma may cause disruption of the ligaments, fractures, or fracture-dislocations. Nerve roots may be involved, or displacement of one vertebra on another (or portions of fractured vertebrae) may anatomically or functionally disrupt the spinal cord, leading to partial or total quadriplegia.

Other injuries of concern are blunt trauma to the anterior neck structures, especially to the larynx, with the potentially hazardous problem of airway obstruction. Additionally, penetrating injuries of the major blood vessels, the trachea, the larynx, or esophagus may be life-threatening.

Most previous studies of spinal injury have been conducted on populations of injured persons identified by their being in a hospital or treatment centers or by review of autopsy findings. Many such studies have included cervical, thoracic, and lumbar injuries, not always differentiating among these anatomic areas.

This paper is limited to the study of cervical injuries of severe (AIS-3)[1] or greater level which were sustained by occupants of a sample of passenger cars in crashes in the U.S. While there is less detail available in this study concerning the sequalae of trauma to the neck (costs, treatment required, etc.) much more information is available about the occupants and vehicle characteristics--seated location within the car, points of contact to which the injuries have been attributed, degree of ejection, etc.

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[1]The Abbreviated Injury Scale: 0-No injury, 1-Minor, 2-Moderate, 3-Severe, 4-Serious, 5-Critical to life, 6-Currently untreatable.

II. LITERATURE REVIEW: INJURY FREQUENCY AND CAUSES OF INJURIES

The extensive German Motor Traffic Insurers' Report on 28,936 drivers and 14,954 other front seat occupants of passenger cars in crashes reported to insurance carriers indicates that severe to fatal cervical spine injuries occur in 0.4% each for drivers and for passengers (1). It was indicated 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 frontal crashes. Tonge et al. (Australia) found cervical fractures or dislocations in 11% of autopsied drivers and 17% of passengers (2). Hossack (Australia), in his review of autopsies on 500 drivers and passengers, found that 7% had cervical fractures with cord damage (3).

Alker et al. reviewed post-mortem x-rays of 146 consecutive traffic accident autopsies (probably including pedestrians); 21% had radiographic evidence of cervical spine injuries (4). Bucholz et al. x-rayed the cervical spine of 100 motor vehicle crash victims, and following autopsy, found that 24% had cervical fractures or fracture-dislocations. They indicated that neither gross inspection (5-6% incidence) nor radiography (21% incidence) alone will uncover all occult cervical lesions (5).

Although there have been a smattering of articles on laryngeal trauma in the clinical literature (6-13), there are no data available on the frequency of injuries to the anterior neck (throat) structures. Most data on the laryngeal injuries are clinical case reviews, with most authors agreeing that such injuries are due to blunt trauma to the throat from impacts to the steering wheel rim or the upper edge of the instrument panel. Tonge et al. reported an autopsy injury incidence of 9% to the anterior throat structures in 500 car drivers and passengers (2). Specific types of injuries and their severity were not indicated. Most of these car occupants (65%) died of head and/or chest injuries.

A national estimate of the number of persons in the U.S. sustaining "spinal cord injury" each year--the definition including all kinds of paralysis or nerve damage--has been made by Kraus et al. in their study of hospital records and review of autopsy records in 18 northern California counties (14). Of an estimated 11,200 persons with spinal cord injuries each year, 4200 will die before reaching a hospital and 1150 more during hospitalization. Approximately 56% of all the spinal cord injuries are the result of highway crashes. Of the highway victims, 19.7% were pedestrians, 9.5% motorcyclists, 3.8% "other"--leaving 67% as vehicle occupants. The authors do not differentiate between cars and trucks, and there seems to be no easy way to get a direct comparison of their figures with the data presented in our study, other than to guess that "most" of the 67% must be in passenger cars. These authors used the International Classification of Diseases codes for defining spinal cord injury, but also reviewed all medical records available for individual cases before including a case in the study. Of 177 cases of "some important impairment" caused by motor vehicle spinal cord injury, 66 were classified as quadriplegic or quadriparetic. The AIS-5 category indicates severe cord damage in the cervical area, and may be compared most directly with the quadriplegic and quadriparetic categories of Kraus.

In another paper Kraus et al. define a spinal-cord injury simply as "an acute traumatic lesion of the spinal cord, cauda equina, or nerve roots, resulting in some degree of motor or sensory deficit or both" (15). Six types of functional impairments diagnosed during hospitalization were utilized. These include (1) quadriplegia (complete lesion at C3 or above); (2) quadriparesis (paralysis in all limbs--complete or incomplete lesion C4-T1); (3) paraplegia; (4) paraparesis; (5) other paralyses (including hemiplegia, Brown-Sequard syndrome, and central cord syndrome) and (6) "other" deficit. The last category accounts for only about 5% of the total, but category 5 represents about 20%. In this paper the authors note that the survival rate for traffic crash injuries is lower than for sports injuries--presumably because of the presence of other associated injuries in car crashes.

A study by the Government Accounting Office (GAO) on "Cost of Spinal Cord Injuries in the United States and Progress in Spinal Cord Regeneration" was done at the request of a group of Washington (state of) congressmen (16). Estimates of lifetime medical costs ranged from $44,000 to $115,000, depending on the extent of the injury, not including lost earnings or other related costs. As reviewed in the GAO report, a 1975 National Institutes of Health study had estimated that there were 100,000 living victims of traumatic spinal cord injury in the U.S., and nearly 10,000 new cases each year. This might be compared with Kraus's estimate of 11,200 (about 5000 of whom die immediately or within a few weeks). The Rehabilitation Services Administration estimates 7000 to 10,000 new cases each year. Various studies estimate different percentages of these injuries resulting from motor vehicle accidents--56% in the NIH (1974), 48% in a California study (1969), and 38% in a Florida study.

In a report for the Insurance Institute for Highway Safety, "The Costs of Motor Vehicle Related Spinal Cord Injuries," Smart and Sanders (1976) reviewed many other reports, and collected data from hospitals to estimate costs of motor-vehicle-related spinal cord injuries (17). National frequency of occurrence estimates were generated from the Kraus data. Motor vehicle spinal cord injuries are estimated at 5,315 annually, with about 2300 of these dying before or shortly after hospital admission. The "national" estimates are made by extrapolating from the California counties study with some adjustment using Federal Highway Administration (FHWA) data on traffic accident rates for the rest of the country.

In his study, "Epidemiology of Spinal Cord Injury," Kurtzke (1975) reviews the Kraus study and suggests that the higher estimates provided by Kraus (than in other studies reviewed) are probably real (18).

III. DATA SOURCES

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 mentioned above have been made from clinical surveys. Recently, a large set of automobile crash injury reports have become available for analysis. This, the National Crash Severity Study (NCSS), is a major accident data collection program of the National Center for Statistics and Analysis of the National Highway Traffic Safety Administration. Available in this data bank are detailed crash configuration information, descriptions of injuries and their sources (contacts), and a quantitative description of vehicle damage. Crashes in this study were selected on a strict stratified sampling plan, and have some potential for making projections to a national population.

IV. INJURY CLASSIFICATIONS

The Abbreviated Injury Scale (AIS) is used in the NCSS file to categorize the severity of injury.

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.

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, outcome (sequelae) of injuries are intentionally not coded; yet outcome, i.e., quadriplegia or quadriparesis as reported in other studies, would most likely be at the AIS-5 level of severity.

V. DATA ANALYSIS

A. Overview

In the NCSS program, the detailed accident and injury data were collected from investigations conducted by professional teams operating in eight regions of the United States. During the period from January 1, 1977 through March 31, 1978, 6,628 accidents were investigated and computerized. In these accidents there were 8,616 towaway passenger cars containing 14,491 occupants.

For 10,151 of the 14,491 occupants, detailed injury information was available from qualified medical sources. Most of the discussion in this report will be based on those for which complete injury information was available.

Autopsies were not available for about half of the fatally injured occupants, and it is likely that many of these sustained severe neck injuries which would add to the total counts. On the other hand, there is apparently little missing data for persons with severe neck injuries who survived. Most persons who sustained these injuries were in the category sampled at 100%, and thus little weighting of the data is required to estimate the total number of severe neck injuries in the NCSS population. The accidents were sampled in such a way that the total population can be reconstructed. For the 15-month period of the data considered here, the total estimated occupant population (i.e., the number of persons who were occupants of passenger cars towed for crash damage within the NCSS sites) is 62,026. Figure 1 shows the relative incidence of neck injury in the total NCSS occupant group. Most of the frequencies in this report will be based on the reconstructed (weighted) 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 (unweighted) form. Appropriate notation as to whether data are weighted or not will be provided.

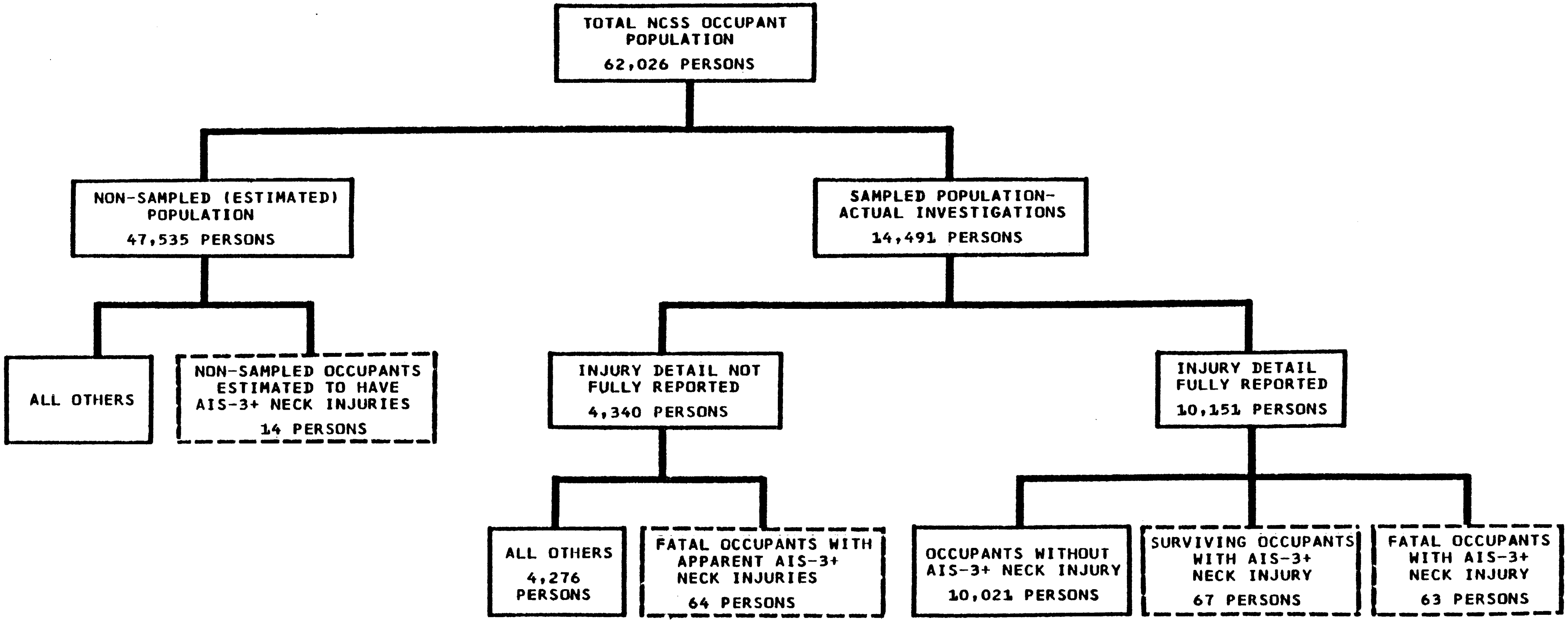

Figure 1
The Study Population
(Broken-line boxes represent persons with AIS-3+ Neck Injuries)

B. Frequency

The incidence of the more severe (AIS 3-5) or fatal (AIS-6) neck injuries is low. Of the 10,151 occupants (actual not weighted) in the NCSS file with medical information, 131 had such neck injuries. Of the 131, 63 were killed, with 53 having a fatal neck injury. A small number of these neck injuries occurred in crashes sampled at less than 100%, and the weighted or reconstructed number of neck-injured persons is 145. The field notes for fatal accident cases for which full medical reports were unavailable, have been studied in detail by us. As a result of this review, 64 additional persons were found who had sustained severe to fatal neck injuries (most of these being fatal). Therefore, of the 62,026 occupants of passenger cars, 209 (0.33%, or one person in 300) were reported to have sustained an AIS 3-5 or fatal neck injury. The distribution of the AIS level for neck injuries and for degree of ejection are shown in Table 1.

TABLE 1
Neck Injury Severity Distribution
Ejection vs. Containment
(Weighted Data)

Neck Injury AIS Level	Not Ejected	Ejected	Unknown if Ejected	TOTAL
0	58,395	529	688	59,612
1	2,091	38	44	2173
2	30	1	1	32
3	62	12	3	77
4	7	0	3	10
5	9	3	1	13
Fatal	62	29	18	109

As noted in the literature review above, the occurrence of neck injuries in fatalities is often underreported. Alker et al. and Bucholz et al. found that upon careful examination, 21-24% of motor vehicle fatally-injured occupants had demonstrable neck injuries (4,5). The findings from the NCSS data seem consistent with this. Of the fatalities for which detailed injury information was available, 20% (53 of 264 fatalities) were reported to have neck fractures.

C. Ejection (Weighted Data)

Of the 209 (weighted) AIS-3 or greater neck injured occupants, 140 were not ejected (67%). Of the remaining 69 car occupants, 44 were ejected from the car. Of all the occupants not ejected, only 0.2% had the more serious or fatal neck injury, compared to 7.2% of those ejected, a frequency 36 times greater.

D. Severity Comparisons With Other Body Areas (Unweighted Data)

A comparison of the AIS 3-5 level or fatal neck injuries with the worst injuries elsewhere in the body indicates that the neck was the more seriously injured body area in 62% of these occupants.

E. Sex Differences (Weighted Data)

One hundred twenty-four males sustained the more severe or fatal neck injuries, compared to 85 females (Table 2). This is 0.32% of all males and 0.29% of all females in the reconstructed NCSS population.

F. Age (Weighted Data)

No specific age group is immune to 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 (0.12%) and twice as often as do those older than 25 years (0.23%).

Occupants in the age range 16 to 25 years, in general, are involved in more severe 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 changes in velocity) recorded for vehicles in crashes. For all 16-25 year old occupants, the average Delta-V in the NCSS cases was 16.4 miles per hour, as compared with 14.7 miles per hour for younger occupants than 16, and 14.4 miles per hour for those older than 25. One may infer that the "age" effect noted above--i.e., a higher frequency of severe and greater neck injuries to 16-25 year olds--is really the result of more severe crashes rather than an anatomical susceptibility to injury.

TABLE 2
The More Serious Neck Injuries--AIS 3-5 and Fatal

AGE	MALE	FEMALE	TOTAL
0-15	5	3	8
16-20	40	27	67
21-25	26	23	49
26-30	11	6	17
31-35	11	5	16
36-40	2	0	2
41-45	5	7	12
46-50	10	2	12
51-75	14	12	26
TOTAL	124	85	209

G. Seat Position (Weighted Data)

Drivers predominate in this series of AIS-3+ neck injuries, but only because drivers predominate in the whole NCSS population. The neck injured drivers constitute 0.32% of all drivers; right front passengers with neck injuries constitute 0.41% of all right front occupants; and rear seat occupants have a neck injury frequency of 0.27%.

H. Crash Type (Weighted Data)

The type of crash is clearly related to the occurrence of the more severe neck injuries (Table 3). 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.

TABLE 3
Severe to Fatal Neck Injuries by Crash Type
(Reconstructed Population)

Principal Damage to Car	All Occupants			Ejected Occupants		
	Total Occupants	AIS 3-6 Neck Injuries		Total Occupants	AIS 3-6 Neck Injuries	
		Number	Percent		Number	Percent
Top (implies Rollover)	1718	28	1.6%	145	16	11.0%
Side	14,303	79	0.6%	235	12	5.1%
Front	30,395	89	0.3%	114	14	12.3%
Rear	2967	2	≤0.1%	19	1	5.3%
Other and Unknown	12,643	10	≤0.1%	83	0	0.0%

I. <u>Type and Location of Neck Injuries</u> (Unweighted Data)

A review of the more severe neck injuries and fatalities of the 130 car occupants with medical reports indicates that the majority of these injuries are located in the posterior aspect of the cervical region, i.e., the cervical spine and spinal cord. These injuries are tabulated in Appendix A. Fractures are the most frequent cervical injury reported (76%; 100/131 injuries). Of the 131 more severe injuries listed for the 130 car occupants, 53 (40%) led to a fatality, all in the cervical spine. There were 8 individuals who had injuries of level AIS-3 or AIS-4 in the anterior neck, with most of these involving throat structures, including fractures or transection of the larynx or trachea, or lacerations of the neck involving major blood vessels or their branches.

J. <u>Contact Sites Related to Neck Injuries</u>(Unweighted Data)

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 contacts more clearly defined the objects struck and are used in Appendix A.

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 impacts or impacts causing deep lacerations (Appendix A).

For those not ejected from the car, the more serious or fatal neck injuries are more often associated with windshield contacts. Approximately one-third of the car occupants with such neck injuries had head/windshield contacts. Less often such injuries are sustained from striking the roof, door, A-pillar, or steering wheel (Table 4). Other car structures are contacted even less frequently.

Although 35 neck-injured occupants are listed as "ejected" or "partially ejected," the majority of the neck-injury-producing contacts were interior vehicle structures. Table 5 shows the contact areas (for unweighted data with medical information) for those ejected.

TABLE 4
Contact Areas for AIS 3-5 and Fatal Cervical Injuries of Non-Ejected Occupants (Unweighted Data)

Contact Area	Number of Occupants	Contact Area	Number of Occupants
Windshield	30	Rear view mirror	3
Roof*	13	Exterior object	3
Door area	10	Hood	2
A-pillar**	8	Headrest	1
Steering wheel	8	Heater/AC duct	1
Instrument Panel	5	Unknown	3
Side window	4		
Seat back	4	TOTAL	95

*"Roof" includes the inside of the roof of the car [9 cases], the side roof rail above the door opening [3 cases], and the sun visor or front of roof over the windshield [1 case].

**A-pillar - the vertical side windshield and roof support.

TABLE 5
Contact Areas for AIS 3-5 and Fatal Cervical Injuries of Ejected Occupants (Unweighted Data)

Contact Area	Fully Ejected Occupants	Partially Ejected Occupants
Intruding Vehicle . .	1	
Intruding Pole or Tree	2	
Side Window	4	
Windshield	3	
Steering Assembly . .	1	1
Right Door Area . . .	1	
Roof	2	
Ground	5	1
Roof Side Rail	1	
Unknown Source	1	
Sunvisor		1
B-Pillar		1

VI. RESTRAINT EFFECTIVENESS

A. Overview

Few of the 130 car occupants with the more severe or fatal neck injuries (and with full medical data) wore belts (Table 6); only two were wearing the lap-shoulder belt , and two others had on a lap belt (both killed). These cases are reviewed individually below:

A. Lap-Shoulder Belted AIS 3-5 Neck Cases

Case No. 1: A 1974 intermediate-size Chevrolet sustained damage at the left front center with an impact direction of 10 o'clock. The car crush extent was severe. The driver sustained a brain concussion and a dislocation of the cervical spine (AIS-3) from head contact to the A-pillar. Minor lacerations about the head were noted. No other injuries were reported. The instantaneous change in velocity at the time of impact (Delta V) was estimated at 27 mph. The Collision Deformation Classification (CDC) for the vehicle was 10-LPAW-5. The case number is #371207051.

Case No. 2: A 1977 Volkswagen subcompact rolled over; the driver sustained a critical neck fracture (AIS -5) from head contact to the roof, serious chest injuries, a moderate level brain concussion and facial lacerations. [Delta V=Unknown; CDC 00-TDHO-3], Case #471008028.

B. Lap Belted Fatal Cases

Case No. 1: A 1973 compact Dodge sustained damage to the front half of the right side of the car with an impact direction of 2 o'clock. The car crush was severe. The front right occupant sustained a brain laceration, a fractured cervical spine (fatal) from A-pillar impact, and critical-to-life thoracic injuries. No other injuries were noted. [Delta V=42 mph; CDC 02.-RFAW-3], Case #170305002.

Case No. 2: A 1971 Ford compact sustained damage to the rear half of the right side . The driver sustained a fractured cervical spine (fatal) from head contact to the door interior. No other injuries were reported. [Delta V=24 mph; CDC 02-RBEW-3], Case #371015004.

TABLE 6
Neck-Injured Persons and Restraint Systems (Unweighted Data)

Restraint System	AIS-Level of Reported Neck Injury								Total
	0	1	2	3	4	5	6	Unknown	
No Belts . .	7471	874	22	56	7	11	46	2	8489(83.6%)
Lap/Shoulder	231	26	--	1	--	1	--	--	259(2.6%)
Lap Only . .	223	24	1	--	--	--	2	--	250(2.5%)
Shoulder Only	2	--	--	--	--	--	--	--	2(.02%)
Passive . . .	2	1	--	--	--	--	--	--	3(.03%)
Child Seat .	15	--	--	--	--	--	--	--	15(.15%)
Unknown . . .	1024	100	2	1	--	--	--	1	1133(11.2%)
TOTAL	8968	1025	25	58	7	12	53	3	10,151(100%)

C. Summary

Although neck injuries of the more severe nature, or cervical fatalities, are relatively infrequent (1,19), one in five fatalities in the NCSS data had a neck fracture of AIS-3 or greater. Few of those wearing belts were so injured. In that many of these neck fracture cases were frontal crashes, it would be expected that lap-torso restraints of any type (belts, airbags) would have markedly decreased the occurrence of the more severe neck injuries.

As has been reported above, a severe neck injury or fatality was found in a high proportion of those ejected. Additionally for the ejected, at least some of the in-car pre-ejection contacts causing neck fractures would have been eliminated, or reduced in impact severity by the use of proper restraint systems.

Review of the contained occupant contact areas indicates that in many the objects related to the neck fracture would not have been contacted had adequate restraints been employed.

VII. 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.

While somewhat more sophisticated projection methods have been developed for some of the NCSS factors, those with nearly complete data, injury detail is missing so often as to not justify the complexity of that method here (20). Rather, a brief discussion of the effects of missing data, combined with a simple population extrapolation of the data, will be presented.

A. Fatalities

In a little more than one-half of the NCSS fatalities an autopsy or medical examiner's report was available. Among these, 53 or 20% were reported to have sustained fatal neck injuries. The remaining half of the NCSS fatalities (for which autopsy or medical examiner reports were unavailable) were reviewed, and a judgment made from descriptive information that in 54 (or 24%) of these cases there was an AIS-6 neck fracture. One way of developing a national projection for this factor (fatal neck injuries) is to multiply the average of these percentages (22%) by the total number of passenger car fatalities in the U.S. as reported by the Fatal Accident Reporting System (FARS) of the National Highway Traffic Safety Administration. For 1977 (essentially the same year as the NCSS data presented here), the number of passenger car fatalities in the U.S. was about 27,000, and 22% of that is 5940. It seems likely, then, that about that number of passenger car occupants per year die principally as the result of a broken neck. Approximately one-third of these (2000) involve ejection.

B. Quadriplegics

While there is a substantial amount of injury data missing in the NCSS study for both fatalities (because there was often no autopsy) and for minor wounds (because there was no medical report), it is believed that the data available for injuries in the AIS-3 to AIS-5 range is substantially complete. The obvious inference is that few if any of the serious neck injuries for investigated cases should be missing, and that those reported should provide the basis for a national extrapolation.

The AIS-scale is not very precise with regard to the consequences of spinal cord injury, although an AIS-5 generally indicates a fracture plus "cord damage." For purposes of this report, we will equate this to the injuries reported by Kraus et al. and others as quadriplegia or quadriparesis--involving cervical damage at C-4 or below. Fractures at this level (or below) without cord damage are coded as AIS-3. Among the NCSS passenger car occupants there were 11 persons who sustained AIS-5 neck injuries and lived. There is some evidence that there may be of the order of 15% missing cases in the NCSS data--i.e., cases which were never reported on although they in fact occurred. The NCSS data under study covered a period of 15 months (25% more than one year). Thus a first estimate of the annual number of AIS-5 neck injury cases would be 11 times 1.15 (to account for the missing cases) times 0.8 (to account for the 15-month-data-taking period), or approximately 10 per year. Since the NCSS regions represent about 2% of the total population of the U.S., we project a total of 50 x 10, or 500 passenger car occupants each year who sustain cervical cord damage and survive. It seems inappropriate to try to place a confidence interval on such a projection, but it may be taken as a best estimate from these data.

Interpreting the data of Kraus et al., we might have expected an annual total of 650 cases of quadriplegia and quadriparesis among passenger car occupants. The NCSS results suggest about 500, and these two estimates may be viewed as equivalent.

Anterior injuries to the neck are observed to be relatively rare. Using the same procedure as above, we would expect about 350 cases nationally, these being distributed (rather uniformly) across AIS-3 to AIS-4. Typical anterior injuries include tracheal fracture or carotid artery damage. Again, it would be inappropriate with these small samples to propose a confidence interval on such a statistic.

VIII. BIOMECHANICS OF NECK INJURIES

A. Cervical Spine

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 (21-30). 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 (rearward bending)--each may be one of two types, associated with compression forces, i.e., compressive hyperflexion or hyperextension or with tensile forces (distraction hyperflexion or hyperextension). In addition there may be rotational forces involved with each of the above. 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. Often these are referred to as a hangman's fracture (21).

In car crashes, neck fractures and/or dislocations are almost always the result of excessive forces transmitted through the cervical spine by the post-cervical 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 (30).

There are no frequency data for the various <u>types</u> 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. (31). Impact tests to eleven 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 (32). Based on human volunteers and cadaver sled tests, they found that the resultant bending moment 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 tolerable values of the neck loading.

B. Throat

The tolerance levels of throat structures are better known. Nahum et al. (1968) tested intact embalmed cadavers with loads of 200-250 lbs., producing marginal fractures of the thyroid cartilage; cricoid cartilages fractured at loads of 175-225 lbs. (33). In 1971, Gadd et al., using embalmed cadavers, showed marginal fractures of the laryngeal cartilages at 90-100 lbs. (34). It is believed that the stiffening of the embalmed tissue about the larynx was responsible for the lower fracture loads.

Most recently, Melvin et al. studied the fracture load level of larynges removed from cadavers (35). For the thyroid cartilage the mean dynamic fracture load was 40.6 lbs., and for cricoid cartilage, 55.5 lbs., significantly lower than 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.

IX. MEDICAL CONSEQUENCES OF THE MORE SERIOUS NECK INJURIES

While the incidence of more serious and fatal neck injuries in this series is relatively low (0.23% of all occupants of towed passenger cars), this group of injuries is unique in the high incidence of fatalities (63 of 130), being the cause of fatalities (53) and the potential long-term cost and degree of disability.

The serious injuries of the neck include: (1) fracture and fracture-dislocations of the cervical spine without spinal cord involvement, (2) injuries resulting in quadriplegia, (3) brachial plexus injuries, and (4) injuries of the larynx, trachea, esophagus and major blood vessels.

DIAGNOSIS AND TREATMENT

A. Fracture and Fracture Dislocations Without Spinal Cord Involvement

Utmost care must be exercised in the early treatment of serious cervical spine injuries. Dislocations are frequently unstable and spinal cord impairment may be induced or aggravated by injudicious movement of the person. Fortunately, most rescue squads and ambulance personnel are well trained in caring for these people. The neck is immobilized by a collar or wrapping, and extrication and transportation are accomplished on a board. Adequate X-rays are a requisite to good treatment. A determination is made as to the bony trauma incurred and if possible the mechanism of injury (extension, compression, etc.), both of which help to determine the therapy which follows.

Immobilization in traction is usually required, often using skull tongs. A special halo apparatus has been employed in more recent years. This immobilizes the head, neck, and thorax or in some cases the head-neck, thorax, and pelvis. The halo allows early mobilization of the patient,tending to prevent systematic complications which occur with prolonged immobilization. If the cervical fractures are accompanied by neither instability nor vertebral body displacement, as with spinous process fractures, the neck may be simply immobilized in a brace and early ambulation is allowed. When skull traction is employed for six to eight weeks, the patient is kept on a frame or special bed which can be rotated or tilted to allow for skin care and the prevention of a number of complications which arise from prolonged immobilization or skin pressure.

In some cases, surgery is undertaken to decompress the spinal cord. Extensive bone removal is required. The unstable injured spine is sometimes fused relatively soon after injury, for fusion often allows for early ambulation.

A variety of braces are employed following treatment by traction or surgery, depending on the amount of healing that has occurred and how much immobilization is required. The brace is worn for an additional six to twelve weeks by which time adequate healing should have occurred.

B. Quadriplegia

Of the several thousand quadriplegics which occur each year in motor-vehicle-related accidents in the United States, it has been estimated that approximately one-third of the survivors have complete paralysis.

Tracheotomy may be required because of respiratory difficulties and problems with pulmonary secretions. A urinary catheter is placed in the bladder to drain the urine. While some automatic function may develop, surgery is often needed to allow urine flow through a spastic bladder neck. The urine is sometimes permanently drained via a cystostomy (a surgical opening into the bladder through the abdominal wall).

Following initial hospitalization, prolonged rehabilitation is required. Fortunately, the government has established regional spinal cord injury rehabilitation centers which give the highest level of care and attention to these victims, preparing them to continue life, often in a productive manner, in the best possible fashion. Ingenious prostheses allow function which has been otherwise lost. Modification of the quadriplegic's surroundings is required (ramps, wide door openings, etc.).

C. Brachial Plexus Injuries

The brachial plexus is composed of nerves arising from the cervical cord from the cervical 5 (C5) level to the first thoracic segment (T1). These individual nerves join and then divide in a complex fashion to form the brachial plexus, before passing into the upper extremity, the structures which they supply.

Brachial plexus injuries occur by direct trauma to the nerves in the neck which are components of the brachial plexus. Stretch or traction on the nerves by forceful lateral bending of the neck towards the opposite side and shoulder depression may injure the upper components of the plexus. Forceful sudden separation of the outstretched upper extremity from the thorax may damage the lower brachial plexus. The latter two types of plexus injury are frequently associated with ejection from the vehicle. If avulsion of the nerve roots is suspected, myelography (injection of a radio-opaque dye into the spinal canal) is helpful in making this determination. Electromyography may also be helpful in delineating the extent of the damage and indicating the prognosis.

Until recently little could be done to benefit these injuries other than immobilization followed by rehabilitation. Tendon transfers from functional muscles to those paralyzed sometimes improve function. In extreme cases, amputation of the paralyzed upper extremity has been carried out. With the advent of the operating microscope, repair of the injured nerves either directly or with grafts has been undertaken with promising results. Prior to the advent of the newer techniques, surgery on the brachial plexus rarely proved rewarding.

Stretch injuries of the brachial plexus may result in permanent weakness, loss of sensation, pain and altered vasomotor responses in the affected upper extremity. The pain may be extreme and is difficult to alleviate.

D. Injuries to the Larynx, Trachea, Esophagus, and Major Blood Vessels

Injuries to these organs usually occur by direct impact, and, if sufficient force is applied, crushing or ruptures of these structures occur by compression against the underlying anterior aspect of the cervical spine.

The semi-rigid larynx may be fractured or crushed, resulting in difficulty with breathing. Intubation of tracheotomy may be life-sparing in these cases. The vocal cords may be damaged directly or through impairment of the laryngeal nerves, resulting in hoarseness or loss of voice.

The trachea, which is the downward continuation of the larynx to the lungs, may be injured in manners similar to the larynx. The major problem with injury is airway obstruction. Tracheotomy may be required acutely or even permanently if the damage results in significant scarring.

The great vessels of the neck (jugular veins and carotid arteries) may be lacerated, possibly resulting in rapid death by exsanguination. Digital pressure applied appropriately by those first on the accident scene may be life saving. Blunt trauma to the carotid arteries may result in thrombosis (blood clot). The manifestations of carotid thrombosis are varied but can be catastrophic, with hemiplegia (paralysis on one side), loss of speech, or death . Surgery on the major neck vessels for repair of lacerations needs to be carried out promptly. Later surgery may offer re-establishment of cerebral circulation through thrombectomy (removal of a blood clot) or by bypass procedures. Trauma to the vocal cords within the larynx may lead to permanent hoarseness or loss of the voice. Severe injury to the larynx or trachea may require permanent tracheostomy. Scarring of the esophagus can cause permanent difficulty in swallowing and may require chronic dilatation.

COMPLICATIONS OF THE MORE SERIOUS CERVICAL INJURIES

A. Cervical Fractures and Fracture Dislocations Without Spinal Cord Involvement

In spite of adequate immobilization, including skeletal traction and bracing, instability may be present. This could be a threat to the intact spinal cord and also could prove to be a painful condition which would necessitate a spinal fusion later on. Even when adequate healing has occurred, degenerate changes may occur and result in limited range of motion and pain. Uncommonly, as part of the healing process, stenosis (closing) of the spinal canal develops with impingement on the spinal cord or roots, leading to compromise of function and pain. Decompression, with or without fusion, would be required in these cases.

Fractures and fracture dislocations of the cervical spine without spinal cord injury may result in only a limited range of neck motion, a sensation of grating, and pain. Fortunately, other than in compensible situations, or people with emotional instability, these symptoms rarely are disabling. On the other hand, quadriplegics retain great disability. The average quadriplegic spends over two years in the recovery and rehabilitative phases. One-third of the complete quadriplegics return to either employment, school, household work, or other productive activities.

About half of the incomplete quadriplegics do the same. The life style of these individuals, as well as that of close family members, is drastically altered. This contributes to emotional problems in all parties concerned.

B. Quadriplegia

Complications are frequent in these quadriplegic patients. It has been suggested that most general hospitals are not adequately equipped to properly care for these patients. There are, of course, many factors which contribute to complications in these patients, some of which are difficult to control.

Decubitus ulcers (breakdown of the skin) are the most common complication and occur in over 80% of the cases. Frequent turning of the patient along with good general skin care tends to prevent this problem. Urinary tract infections are also another frequent complication, and relate to the need for the use of catheters in the bladder. Appropriate antibiotic treatment tends to neutralize the problem, but antibiotics frequently are required over protracted periods of time because of the nature of the bacteria which cause the infection, in the face of the continuation of the same factors which lead to the infection initially, i.e., urinary stasis and the in-dwelling catheter. Kidney stones frequently are formed and relate in part to the extreme decalcification which occurs throughout the body of the quadriplegic . Pneumonia occurs, especially early in the course of events and relates in part to inability of the individual to adequately cough and eliminate accumulated secretions, and also by virtue of aspiration of blood and liquids. Contracture deformities of the limbs may develop late and relate in part to muscle spasticity which may be difficult to overcome. Regular passive exercising of the limbs helps to prevent contractures. Thrombophlebitis in the deep veins of the lower extremities in a life-threatening complication. The process may extend into the pelvic veins and necessitate ligation of the inferior vena cava in the abdomen. Pulmonary embolism from the thrombi in the veins can be a cause of sudden death in these patients. Frequent passive movement of the lower extremities along with the use of proper elastic support stockings tends to reduce the occurrence of these complications.

X. CONCLUSIONS

Previous studies of highway-induced cervical injuries have been based on clinical reviews, and not from 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 towaway passenger cars, 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 AIS-3 to AIS-5 or fatal. For contained occupants (i.e., persons who were not ejected from their cars) this rate was one in 433. For ejected occupants, the rate was one in fourteen. Yet many of those ejected contacted in-car structures to sustain the cervical injury prior to, or in the process of, being ejected.

A comparison of the AIS 3-5 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 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%) had a cervical spine fatality. There were 8 individuals who had injuries of level AIS-3 or AIS-4 in the anterior neck, with most of these involving 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 impacts or impacts causing deep lacerations .

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

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. Many of these severe neck injuries could have been prevented by the use of available restraint systems, or (in many cases) by passive restraints.

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APPENDIX A

Non-Ejected Occupants
Neck Injury Descriptions by Contact Areas

<u>Windshield</u>

1 Fracture/separation of cervical vertebrae (AIS 3)

2 Fracture/dislocation of atlanto-occipital joint with laceration of medulla (AIS 6)

3 Fracture/dislocation of 2nd cervical vertebra (AIS 6)

4 Avulsion fracture of C2 anteriorly (AIS 6)

5 Fracture of C2 posterior elements (AIS 3)

6 Fracture of posterior C2 with 40% subluxation on C3 (AIS 3)

7 Oblique fracture through body of C1 (AIS 3)

8 Laceration of right carotid artery (AIS 3)

9 Fractured vertebra, no detailed medical data (AIS 6)

10 Fractured vertebra, no detailed medical data (AIS 6)

11 Fracture C7 spinous process (AIS 3)

12 Fracture C1 (AIS 3)

13 Fracture spinous process C6; ring fracture C7 with partial nerve loss (AIS 5)

14 Fracture/dislocation C6-7; total lower paralysis (AIS 5)

15 Subluxation C2, C4, and C5 (AIS 3)

16 Fractured vertebra, no detailed medical data (AIS 5)

17 Subluxation C5-6 (AIS 5)

18 Fractured vertebra, no detailed medical data (AIS 6)

19 Deep laceration right inframandibular area with severed external carotid artery branch (AIS 3)

20 Fractured vertebra, no detailed medical data (AIS 6)

21 Chip fracture C7 vertebral body (AIS 3)

22 Linear fracture odontoid process C2 (AIS 3)

23 Severe laceration upper neck through mouth (AIS 3)

24 Fracture/dislocation C5 (AIS 3)

25 Fracture upper cervical vertebra: necrosis of cord (AIS 6)

26 Fracture spinous process C1 (AIS 3)

27 Subluxation of C2, C3 with fracture of C2, no cord damage (AIS 3)

28 (AIS 3) Fracture/dislocation C1-3, transection of cord (AIS 6)

29 Subluxation C3-4 (AIS 3)

30 Comminuted fracture transverse process C7, T1 (AIS 3)

Door Area

1 Fracture/dislocation of atlanto-occipital joint (AIS 6)

2 Fracture atlas (AIS 5)

3 Fracture vertebra, no detailed medical data (AIS 6)

4 Fracture C7-T1 (AIS 3)

5 Fracture vertebra, no detailed medical data (AIS 3)

6 Fracture left uncinate process C6 (AIS 3)

7 Fracture, luxation C4 (AIS 3)

8 Fracture vertebra, no detailed medical data (AIS 3)

9 Subluxation of C2-C3 (AIS 3)

10 Separation of atlanto-occipital joint Z(AIS 6)

Roof

1 Atlanto-occipital dislocation, foramen magnum compromised causing transection of medulla (AIS 5)

2 Comminuted fracture of C6 (AIS 3)

3 Fracture C6 with paraplegia (AIS 5)

4 Fracture C5 (AIS 3)

5 Fracture, subluxation C3-C4, teardrop fracture C5, permanent paralysis neck down--slight movement right side (AIS 5)

6 Displaced fracture C5-C6 quadriplegia (AIS 5)

7 Fracture C2-C3 (AIS 6)

8 Transverse fracture C2 (AIS 6)

9 Fracture vertebra, no detailed medical data (AIS 3)

A-Pillar

1 Fracture C2, Cord transection separating medula and pons (AIS 6)

2 Compression fracture C6 (AIS 3)

3 Extensive lacerations medulla (AIS 6)

4 Fracture C1, neurological damage and partial avulsion of medulla from pons (AIS 6)

5 Fracture lateral mass C7 (AIS 3)

6 Fracture, subluxation of C4 (AIS 3)

7 Displaced cervical fracture (AIS 3)

8 Fracture C1 (AIS 3) Steering Wheel

1 Trachea Transection (AIS 4)

2 Fracture/dislocation C5-C6, cervical fusion; quadriplegia (AIS 5)

3 Fracture C6 spinous process (AIS 3)

4 Fracture C2 and C5 (AIS 3)

5 Fracture larynx (AIS 3)

6 Undisplaced fracture tip of spinous process C7 (AIS 3)

7 Fracture larynx and cricoid (AIS 40

8 Subluxation C3, 4; fracture right lamina C3 (AIS 3)

Side Window and/or Frame

1 Fracture 7th cervical vertebra (AIS 3)

2 Fracture with displacement of C2 on C1 (AIS 6)

3 Fracture vertebra, no detailed medical data (AIS 6)

4 Fracture C5 (AIS 3)

Seat Back

1 Longitudinal fracture of C2 (AIS 3)

2 Fracture C2-C3 with cord damage, 15-30% disability (AIS 5)

3 Subluxation C3-C4 (AIS 3)

4 Cervical spine dislocation (AIS 3)

Rearview Mirror

1 Fracture transverse process C7 (AIS 3)

2 Transverse laceration with muscular and veinous involvement (AIS 3)

3 Hairline fracture of odontoid (AIS 3)

Side Roof Rail

1 Fracture C2 (AIS 3)

2 Fracture/dislocation involving C1 with partial separation of pons from medulla (AIS 6)

3 Undisplaced fracture through pedicle of C4--possible chip fracture of C5 (AIS 3)

Unknown

1 Anterior fracture, base of skull lacerating cord (AIS 6)

2 Laceration of atlanto-occipital joint--no medical data on fracture (AIS 6)

3 Spinal cord lacerated at occiput (AIS 6)

Intruding Object

1 Dislocation cervical spine, transection of spinal cord (AIS 6)

2 Atlanto-occipital dislocation (AIS 6)

3 Fracture C2 (AIS 3)

Instrument Panel

1 Fracture causing separation of atlanto-occipital joint (AIS 6)

2 Fracture larynx (AIS 3)

3 Comminuted fracture C2, associated cord damage; fracture right
thyroid cartilage with hemorrhage (AIS 5)

4 Fracture C7 vertebral body (AIS 3)

Intruding Hood

1 Fracture vertebra, no detailed medical data (AIS 6)

2 Subluxation C3, 4, 5; anterior body fracture of C4, quadriplegia
(AIS 6)

Headrest

1 Fracture C2 (AIS 6)

Heater/AC Ducts

1 Fracture vertebra, no detailed medical data (AIS 6)

Glove Compartment

1 Laryngotracheal fracture (AIS 4)

Sunvisor/Header

1 Comminuted undisplaced fracture of odontoid, fracture spinous process of C6 (AIS 3)