Vernard I. Adams,[1] *M.D.*

Neck Injuries: III. Ligamentous Injuries of the Craniocervical Articulation Without Occipito-atlantal or Atlanto-axial Facet Dislocation. A Pathologic Study of 21 Traffic Fatalities

REFERENCE: Adams, V. I., **"Neck Injuries: III. Ligamentous Injuries of the Craniocervical Articulation Without Occipito-atlantal or Atlanto-axial Facet Dislocation. A Pathologic Study of 21 Traffic Fatalities,"** *Journal of Forensic Sciences*, JFSCA, Vol. 38, No. 5, September 1993, pp. 1097–1104.

ABSTRACT: Craniocervical ligamentous injuries without dislocation of the occipito-atlantal or atlantoaxial motion segments have been described rarely if at all. Among 155 traffic fatalities were 21 persons with such injuries. Among the 21 fatalities were 20 alar ligament injuries, eight tectorial membrane injuries, and ten injuries of the subaxial cervical spine. All 21 had craniocerebral trauma, including twelve with skull fractures, seven with facial or mandibular fractures, eight with subdural hemorrhages, twelve with subarachnoid hemorrhages, seven with cerebral contusions, five with cerebral lacerations, two with midbrain lacerations, nine with pontomedullary lacerations, and four with spinomedullary injuries. The mechanism of death was acute neurogenic shock in seven victims, acute neurogenic shock in combination with other physiological derangements in six, acute neurogenic respiratory arrest in three, brain swelling in two, and mechanisms unrelated to head and neck trauma in three victims. In six victims, the neck injury did not contribute to death. No conclusions regarding the biomechanical mode of injury are drawn.

KEYWORDS: pathology and biology, neck injuries, craniocervical dislocating, motor vehicle accidents, musculoskeletal system, neurogenic shock

Although descriptions of occipito-atlantal and atlanto-axial dislocations exist in the clinical and forensic literature, other sprain injuries of the craniocervical articulation, not involving these motion segments and their facet joints, have been described rarely if at all. In this study is described a series of high neck injuries involving tectorial membrane and alar ligament derangements without associated dislocations or laceration of the occipito-atlantal or atlanto-axial motion segments. Most of the subjects also had injuries of the subaxial cervical spine, and most had significant craniocerebral trauma.

Methods

The injuries described in this report derive from a series of 155 traffic fatalities autopsied by the author in Massachusetts between 1985 and 1987 and described in detail elsewhere [*1*,*2*]. Autopsy examination of the neck was done according to previously published

Received for publication 6 July 1992; revised manuscript received 11 Jan. 1993; accepted for publication 6 Feb. 1993.

[1]Department of Pathology and Laboratory Medicine, University of South Florida and Chief Medical Examiner, Hillsborough County, FL.

techniques [3,4]. In 15 cases, the spinal canal was examined by anterior removal of the vertebral bodies and visualization through the foramen magnum, and in six subjects a posterior approach was used.

Results

Twenty-one subjects had craniocervical derangements not classified as occipito-atlantal or atlanto-axial dislocations. They were from a variety of crash types. Four were occupants of vehicles struck on the front end; three of these were drivers and one was a rear seat passenger. Seven were from side-impact collisions, five of whom were near-side and two of whom were far-side occupants. Three were cyclists and three were pedestrians. Two were in unusual crashes; one of these subjects had deliberately jumped from the passenger compartment of an automobile moving at high speed, and the other was an occupant of a vehicle which rolled over and then had a significant impact to the top of the vehicle. Two subjects were occupants of vehicles which had impacts which were not further classified because of insufficient information (Table 1).

Restraint belts were worn by two of the persons in side impact collisions and by both victims in the unclassified collisions. One of the belted side-impact victims was partly ejected. His automobile came to rest upside down with the decedent suspended by the neck from his restraint strap, partly ejected. Another side-impact victim, not known to be belted, was fully ejected. Both subjects in the unusual collisions were ejected. One voluntarily exited the vehicle, as described, to commit suicide (Tables 1 and 2).

The decedents comprised fourteen men, one boy, five women, and one girl. The men ranged in age from 16 to 63 years, with five in their twenties. They ranged in height from 163 to 188 cm (5′4″ to 6′2″), and in weight from 66 to 109 kg (146 to 239 lb). The boy

TABLE 1—*Crash type and fractures of the mandible, face and skull.*

Case	Type of crash	Fracture			
		Mandible	Face	Vault	Base
1	Front	+	+	. . .	. . .
2	Front	. . .	. . .	+	+
3	Front	+	. . .	. . .	. . .
4	Front	. . .	. . .	. . .	. . .
5	Side	. . .	. . .	+	+
6	Side	. . .	+	. . .	. . .
7	Side	. . .	. . .	. . .	. . .
8	Side[b]	. . .	. . .	+	+
9	Side	+	+	. . .	+
10	Side[a]	. . .	. . .	. . .	. . .
11	Side	. . .	. . .	. . .	. . .
12	Cyclist	. . .	. . .	. . .	+
13	Cyclist	. . .	. . .	+	+
14	Cyclist	. . .	. . .	+	+
15	Pedestrian	. . .	. . .	. . .	. . .
16	Pedestrian	. . .	. . .	+	. . .
17	Pedestrian	. . .	. . .	. . .	+
18	Jumper[a]	. . .	+	. . .	+
19	Rollover/top[a]	+	+	+	+
20	Occupant[c]	. . .	+	+	+
21	Occupant[c]	. . .	. . .	. . .	. . .

[a]Ejected.
[b]Partly Ejected.
[c]Not Further Classified.

TABLE 2—*Age, sex, restraint belts and blood alcohol.*

Case	Age (years)	Sex	Belts[a]	Ethanol[b]
1	57	M	0	–
2	15	F	–	–
3	47	M	0	+
4	27	M	–	–
5	34	M	+	+
6	32	M	0	+
7	60	M	–	–
8	27	M	+	+
9	45	F	0	–
10	45	M	0	–
11	55	F	0	0
12	27	M	–	+
13	29	M	–	+
14	9	M	–	–
15	76	F	–	–
16	63	M	–	–
17	7	F	–	0
18	38	F	–	–
19	16	M	–	+
20	22	M	+	+
21	18	F	+	–

[a] + = fastened.
– = not fastened or not applicable.
0 = unknown.
[b] + = detected.
– = not detected.
0 = not tested.

was nine years old, 142 cm (4′8″) tall and weighed 48 kg (105 lb). The women ranged in age from 15 to 76 years, in height from 157 to 173 cm (5′2″ to 5′8″) and in weight from 55 to 86 kg (122 to 190 lb). The girl was seven years old, 130 cm (4′3″) tall and weighed 24 kg (52 lb) (Table 2).

Four subjects had direct impacts to the neck. Two had anterior impacts to the neck, one had a left anterior impact, and one was impacted on the right side of the neck. Impacts to the head could be found on all surfaces of the head; no discernible clustering, or correlation with particular directions of impacts to the torso were found. All subjects had evidence of head impact.

Thirteen of the 21 subjects had injuries of the dura mater and tectorial membrane. Eight of these injuries were lacerations and five were characterized by loosening of the dura and tectorial membrane from the dens and clivus. Eight had neither laceration nor loosening of the tectorial membrane (Table 3).

Twenty of the 21 had injury of one or both alar ligaments. Two had lacerations of both alar ligaments. Three had lacerations of one alar ligament and sprain of the contralateral alar ligament. One had an avulsed occiptal condyle and bilateral alar sprain, representing the exceptional instance of bone failing before ligament in tension. Ten others had sprains of both ligaments, and four had unilateral alar ligament sprains. One had no sprains of the alar ligaments. One had a full and one had a partial laceration of the transverse ligament (Table 3).

Ten of the 21 subjects had one or more accompanying subaxial neck injuries. These were evenly distributed between the C2-C3 disc and the C7-T1 disc, and involved separations of discs from end plates, and lacerations and sprains of the anterior ligament in various combinations. In addition, five of these ten had posterior column injuries involving

TABLE 3—*Trauma of vertebral ligaments, brain, and spinal cord.*

Case	Dura and Tectorial Membrane (Lac = Laceration)	Alar Ligaments (L = Laceration S = Sprain)	Subaxial Anterior Column (denotes trauma of anterior column)	Brain and Spinal Cord (+ denotes laceration or contusion)				
				C	MB	PM	SM	SC[c]
1	Lac	— —	+	. . .	. . .	+	+	. . .
2	—	S L	−	+	+	+	. . .	. . .
3	Lac	S L	+	. . .	. . .	. . .	+	+
4	Lac	L L	+	. . .	. . .	+	. . .	+
5	—	S S	−	. . .	. . .	+	. . .	. . .
6	Lac	L L	−	. . .	. . .	+	. . .	. . .
7	Loose	S S	−	. . .	. . .	. . .	. . .	. . .
8	Loose	S S	−	+	. . .	. . .	. . .	+
9	—	S S	+	. . .	. . .	. . .	. . .	+
10[a]	Lac	L S	+	. . .	. . .	+	. . .	+
11	Lac	S S	−	. . .	. . .	. . .	. . .	. . .
12	Loose	— S	+	. . .	. . .	. . .	+	. . .
13	Loose	S L	+	. . .	. . .	+	. . .	. . .
14	—	S —	−	. . .	. . .	. . .	. . .	. . .
15[a]	—	S S	+	. . .	. . .	. . .	. . .	. . .
16	Lac	S S	+	. . .	. . .	+	. . .	+
17	—	S —	−	. . .	. . .	. . .	. . .	. . .
18	Lac	S S	+	+	+	+	. . .	+
19[b]	—	S S	−	+	. . .	. . .	+	. . .
20	—	S —	−	+	. . .	. . .	. . .	. . .
21	Loose	S S	−	. . .	. . .	. . .	. . .	. . .

[a] = laceration of transverse ligament.
[b] = fracture of occipital condyle.
[c] C = Cerebrum; MB = Midbrain; PM = Ponto-medullary junction; SM = Spino-medullary junction; SC = Spinal cord.

lacerations of the ligamentum flavum and posterior longitudinal ligament. One of these five subaxial injuries was at the C2-C3 motion segment. Of the five, two were at the C6-C7 motion segment and involved laceration of the facet joint capsule. One of these two was accompanied by the transverse ligament laceration noted above. One of the five had fractures of both axial pedicles, accompanying a disc separation at C2-C3, with laceration of the anterior and posterior longitudinal ligaments, constituting a so-called Hangman's fracture (see Fig. 1) [5]. The fifth case involved an oblique fracture-dislocation beginning at the C7-T1 disc and extending caudally and dorsally to end in the posterior elements of T4 (Table 3).

All 21 subjects had craniocerebral trauma of one sort or another. Seven of the 21 subjects had fractures of the vault and base of the skull, four had basilar skull fractures only, and one had a vault fracture only, for a total of 12 subjects with skull fractures, exclusive of the aforementioned avulsion of an occipital condyle. Three of the 21 had both facial and mandibular fractures. Three had facial fractures only, and one had a mandibular fracture only, for a total of seven subjects with facial or mandibular fractures (Table 1).

Eight subjects had subdural hemorrhages. Most were thin; two were thick measurable hematomas, one of which was in the posterior fossa. In one of these two individuals, cardiac massage was performed for 60 minutes. The other had a survival interval of 43 hours. One of the eight subjects had a cerebral aneurysm that ruptured at or near the time of the crash, and which produced both subarachnoid and subdural bleeding. Eleven other instances of subarachnoid hemorrhage were documented.

Seven of the 21 subjects had cerebrocortical contusions, including three instances of contusions underlying fractures. Two of these subjects also had intermediate-type contusions. Five had cerebral hemisphere lacerations of varying degrees. The most extensive lacerations involved a subject in which the brain was traumatically eviscerated (Table 3).

Of the 21 subjects, two had midbrain lacerations, nine had pontomedullary lacerations, four had injuries of the spinomedullary junction (two lacerations, one ordinary contusion and one contusion manifested only by softening), and seven had spinal cord injuries (one laceration, two contusions, and three softenings). One subject had mild degenerative disease of the cervical spine (Table 3).

Eight of the 21 subjects had detectable concentrations of ethanol in the blood. Two of the subjects had blood ethanol concentrations in the .25 to .30% range. One was in the .20 to .25% range, two were in the .15 to .20% range, two were in the .10 to .15% range, and one was in the 0 to .05% range. Ethanol was not detected in eleven subjects, and was not tested in two. The latter two subjects were a seven year old girl, and a 55-year-old woman who sustained rupture of a cerebral aneurysm at the time of her collision, and survived three days (Table 2).

Of the 21 victims, seven died within seconds or minutes of acute neurogenic shock, as defined previously [1]. Two of these had lacerations of the heart and aorta, with hemothoraces of only 100 and 400 mL each.

Six died from the combined effects of neurogenic shock and other lethal mechanisms. Five of the six had rapid deaths. Of these five, one had a cardiac tamponade, one had a constricting cardiac hernia through a pericardial sac laceration, one had lower spinal trauma and a cardiac contusion, one had a pneumothorax, and one had a diseased electrically unstable heart and an aortic dissection. These five individuals all lost vital signs within a few seconds or minutes. The sixth person had a cardiac arrest in minutes from neurogenic shock, was resuscitated, and died three days later from cerebral edema.

Eight of the 21 persons died of mechanisms other than neurogenic shock. Three of these are thought to have had respiratory arrest on the basis of neural trauma; in one of these individuals, ethanol intoxication probably contributed to the respiratory arrest. The remaining five individuals who did not have neurogenic shock had a variety of lethal

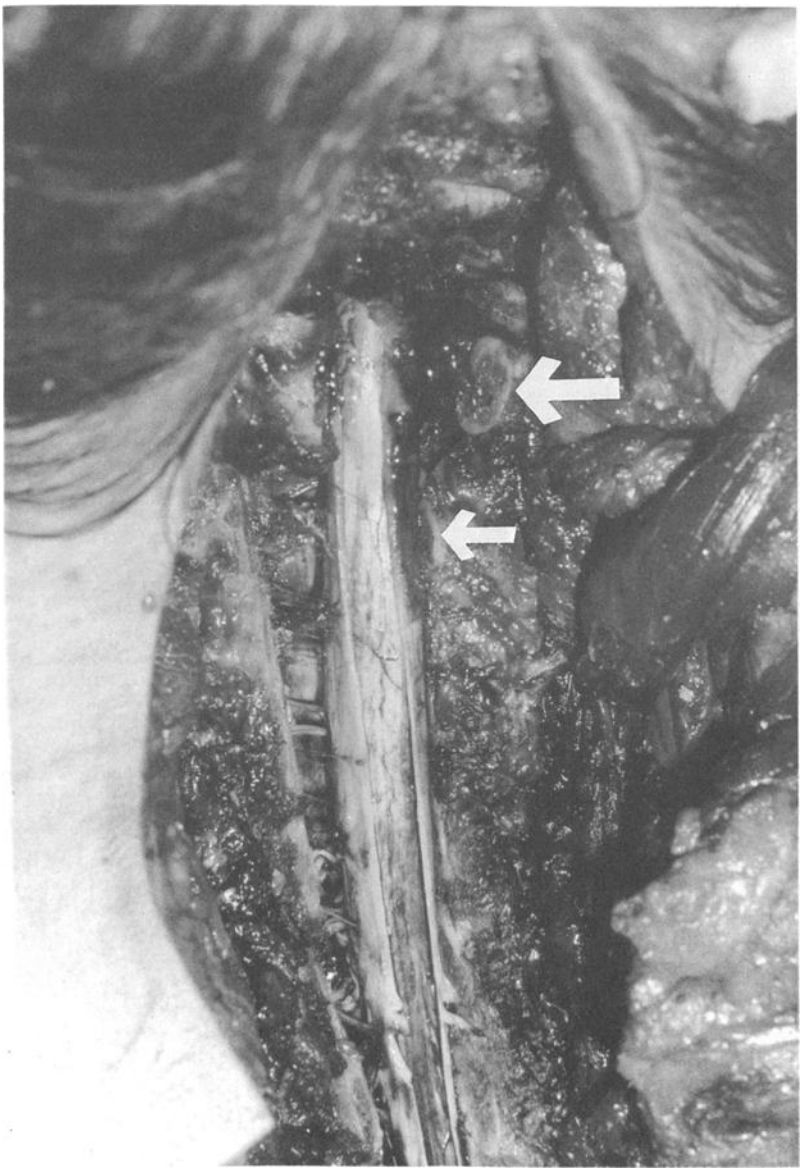

FIG. 1—*"Hangman's fracture," with C2-C3 dislocation and fracture of C2 pedicles. Posterior view, after laminectomy and vertical incision of dura mater, depicting vertebral distraction and subtle narrowing of cord at C2-C3.* Large arrow—*C2 laminectomy.* Small arrow —*C3 laminectomy.*

mechanisms. One bled rapidly from lacerations of the heart and aorta, producing a 2000 mL hemothorax. In one person who died 12 minutes after the crash, the probable mechanism was electrical instability of the heart due to natural disease. In another, retroperitoneal hemorrhage from fractures caused hypovolemic shock with cardiac arrest 30 minutes after the crash. One person with a subdural hematoma died after 14 hours from the effects of brain compression and swelling, and another with cerebral contusions survived 43 hours and succumbed to brain swelling.

Comment

Although a few investigators have studied injuries of the craniocervical articulation [*1*,*12*], to the best of my knowledge none have described isolated traumatic derangements of the alar ligaments and tectorial membrane. Some of the extant studies are radiologic and would not be expected to detect nondisplaced ligamentous injuries [*6*,*10*]. In one study, the creation of specimens for examination entailed excision through the occipito-atlantal articular ligaments, thereby precluding the chance to observe alar and tectorial sprains [*12*].

Among the subjects with occipito-axial ligamentous injuries in this study, two had lacerations of the transverse ligament. The transverse ligament is a dense band that holds the dens snugly against the anterior arch of the atlas and is therefore, an atlanto-dental ligament. These two subjects were the only victims with the atlanto-dental form of atlanto-axial dislocation among the 66 persons with neck injuries in the overall study. Atlanto-axial facet joint dislocation was the more common form of C1-C2 dislocation, with 14 cases reported in a companion report [*2*]. In contrast, clinical reports of atlantodental dislocation are numerous [*2*].

A dominant biomechanical mode of injury, such as extension, translation or rotation, was not identified. Half the alar ligament injuries were symmetric and half were asymmetric, raising the possibility of a rotational component in some injuries. The subaxial anterior ligament sprains could suggest either extension or vertex impact with buckling.

Only three of the 21 had facial or mandibular fractures, in contrast to the greater incidence found with occipito-atlantal and atlanto-axial facet joint dislocations [*1*,*2*]. This may be due as much to a lesser force of impact as it may be to a reduced role of extension and distraction. Nine of 21 subjects had pontomedullary lacerations, which have been customarily associated with hyperextension but that might also be caused by rotation [*1*]. Only four of 21 had direct impact injuries of the spinal cord at the medullary junction. One of these four subjects had laceration of the transverse ligament. Although the injuries of the craniocervical articulation described in this paper were not associated with static dislocation, as judged at the time of autopsy, it is likely that transient dynamic dislocation occurred at the moment of impact.

Nearly instant death, solely from the effects of high neck injury, occurred in nine of the 21 subjects, representing seven deaths from acute neurogenic shock and two from respiratory arrest. In seven cases, including six with acute neurogenic shock and one with respiratory arrest and ethanol intoxication, the neck injury was one of two or more major lethal mechanisms. In six instances the neck injury was not contributory to death. Thus, the occipito-axial sprain injuries were less often lethal than the occipito-atlantal and atlanto-axial dislocations described in the first two parts of this series, in which acute neurogenic shock rapidly felled the majority of the victims [*1*,*2*].

Whereas clinical and radiological studies of neck trauma underdiagnose ligamentous and dislocation injuries, this study may have missed some bony fractures which were not associated with ligamentous damage. Examples would include non-displaced fractures of the anterior ring of C1, and subaxial facet fractures. Inconspicuous bone chips avulsed from vertebral end plates during disc lacerations would not have been tallied separately.

Most occipito-atlantal and atlanto-axial dislocations are associated with hemorrhage in the prevertebral fascia and longus capitus muscles anteriorly. In the absence of such hemorrhage, and in the absence of evidence of facet dislocation visible or palpable through the foramen magnum from above, the craniocervical articulation and spinal column were assessed by anterior but not posterior dissection. Therefore, subtle sprains of the occipito-atlantal and atlanto-axial facet joints were conceivably not detected in this series.

In summary, described herein is a group of craniocervical derangements with a high lethal potential which has not been well described in the medical literature, and which is equally or more common in traffic fatalities than the more widely known occipito-atlantal dislocation.

References

[1] Adams, V. I., "Neck Injuries: I. Occipitoatlantal Dislocation—A Pathologic Study of Twelve Traffic Fatalities," *Journal of Forensic Sciences*, Vol. 37, No. 2, March 1992, pp. 556–564.

[2] Adams, V. I., "Neck Injuries: II. Atlantoaxial Dislocation—A Pathologic Study of Fourteen Traffic Fatalities, *Journal of Forensic Sciences*, Vol. 37, No. 2, March 1992, pp. 565–573.

[3] Adams, V. I., "Autopsy Technique for Neck Examination: I. Anterior and Lateral Compartment and Tongue," *Pathology Annual*, Vol. 25, No. 2, 1990, pp. 331–349.

[4] Adams, V. I., "Autopsy Technique for Neck Examination: II. Vertebral Column and Posterior Compartment," *Pathology Annual*, Vol. 26, No. 1, 1991, pp. 211–226.

[5] Fielding, J. W., Cochran, G. V. B., Lawsing, J. F. III, and Hohl, M. "Tears of the Transverse Ligament of the Atlas: A Clinical and Biomechanical Study," *Journal of Bone and Joint Surgery*, Vol. 56A, 1974, pp. 1683–1691.

[6] Alker, G. J., Jr., Oh, Y. S., and Leslie, E. V., "High Cervical Spine and Craniocervical Junction Injuries in Fatal Traffic Accidents: A Radiologic Study, *Orthopedic Clinics of North America*, Vol. 9, No. 4, 1978, pp. 1003–1010.

[7] Bohlman, H. H., "Acute Fractures and Dislocations of the Cervical Spine—An Analysis of Three Hundred Hospitalized Patients and Review of the Literature," *Journal of Bone and Joint Surgery*, Vol. 61A, 1979, pp. 1119–1142.

[8] Bucholz, R. W. and Burkhead, W. Z., "The Pathological Anatomy of Fatal Atlanto-occipital Dislocations," *Journal of Bone and Joint Surgery*, Vol. 61A, 1979, pp. 248–250.

[9] Cain, C. M. J., Ryan, G. A., Fraser, R., et al., "Cervical Spine Injuries in Road Traffic Crashes in South Australia, 1981–1986," *Australia and New Zealand Journal of Surgery*, Vol. 59, 1989, pp. 15–19.

[10] Cain, C. M. J., Simpson, D. A., Ryan, G. A., et al., "Road Crash Cervical Injuries. A Radiological Study of Fatalities," *American Journal of Forensic Medicine and Pathology*, Vol. 10, 1989, pp. 193–195.

[11] Davis, D., Bohlman, H., Walker, E. A., et al., "The Pathological Findings in Fatal Craniospinal Injuries," *Journal of Neurosurgery*, Vol. 34, 1971, pp. 603–613.

[12] Dorr, L. D. and Harvey, J. P., Jr., "The Traumatic Lesions in Fatal Acute Spinal Column Injuries," *Clinical Orthopedics*, Vol. 157, 1981, pp. 178–190.

Address requests for reprints or additional information to
Vernard I. Adams, M.D.
Medical Examiner Department—Hillsborough County
401 South Morgan St.
Tampa, FL 33602