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Upper Cervical Trauma in Motor Vehicle Collisions

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ABSTRACT: Motor vehicle collisions can cause a variety of injuries in pedestrians and vehicle occupants. Fatal and nonfatal trauma to the upper cervical spine, that is, atlanto-occipital junction, atlas and axis, can be part of this spectrum. Certain distinctive injuries (for example, "hangman's fracture") which occur result from the unique anatomic structure of this area and the various disruptive forces such as extension, distraction (tension), compression (axial loading), shear, and inertia generated during collision. Correlation of autopsy findings or radiological information of these cervical injuries or both with scene investigation can be informative not only in the determination of morbidity and mortality, but also in the assessment of injury mechanisms and improvements in occupant protection.

KEYWORDS: pathology and biology, motor vehicle accidents, injuries

Motor-vehicle-related trauma of the occipital-atlanto-axial complex ("the cervicocranium") is less common than injuries of the lower cervical spine [*1*]. The unique structure of the upper cervical spine must be appreciated to understand the injury biomechanics of eight representative cases investigated by our research team.

The ligaments (includes anterior and posterior atlanto-occipital ligaments, tectorial membrane) between the occiput and atlas (the first cervical vertebra) are fibrous and inelastic relative to other levels of the cervical spine [*2*] (Fig. 1). The atlas and axis (the second cervical vertebra) are structurally modified to allow head mobility and transmit the weight of the cranium to the rest of the unmodified cervical spine; however, the anatomy of these two vertebra makes them vulnerable to impact. The atlas (Fig. 2) is a bony ring lacking a vertebral body. Large lateral masses articulate superiorly with the occipital condyles. The anterior and posterior arches are potentially weak. The axis (Fig. 3) has a vertebral body with an odontoid process. The laminae and spinous process are stout but the pedicles are relatively weakened by the transverse foramina. Note that the spinal canal at the C1-C2 level is wider than the lower cervical spine [*1*].

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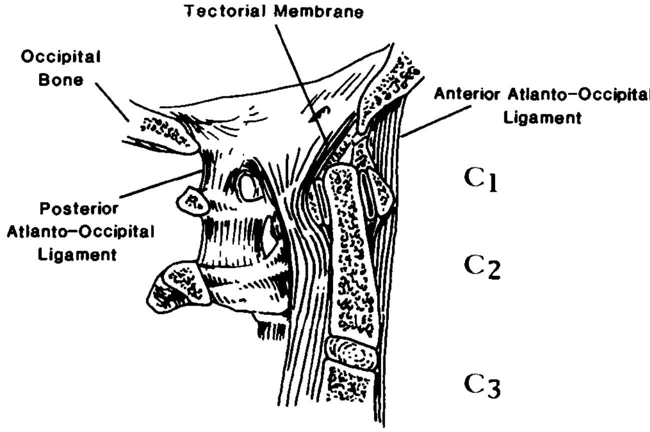

FIG. 1—*Median section through occipital bone and upper cervical spine.*

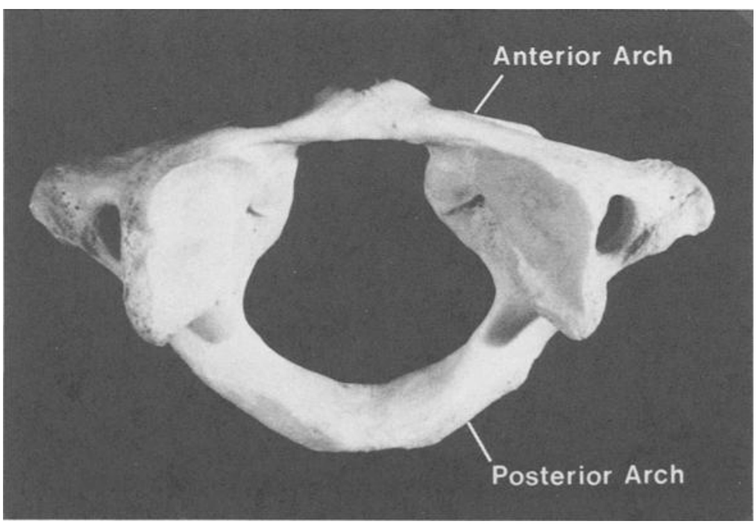

FIG. 2—*Atlas (C1), superior view.*

Atlanto-Occipital Level

Three cases of instantaneously fatal atlanto-occipital dislocation were studied.

Case 1

A 39-year-old fully belted female driver of a van traveling 100 km/h (60 mph) collided with the rear of a transport trailer going 30 km/h (20 mph). The posterior part of the hood, the instrument panel, and the steering column displaced rearward as her head impacted on the dashboard. High-intensity extension and shear forces generated between the head and the

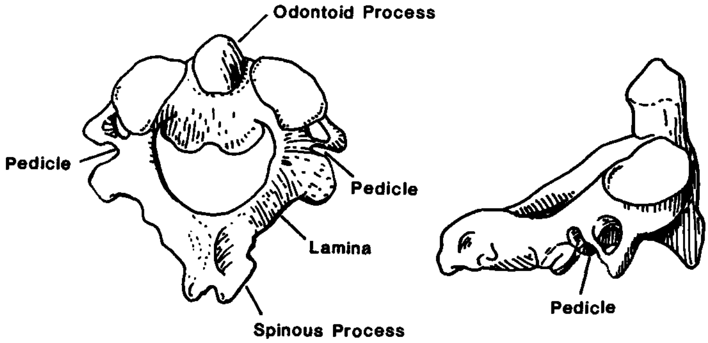

FIG. 3—*Axis (C2), superior view. Note thin pedicles and wide spinal canal.*

rest of the body tore the atlanto-occipital ligaments. A brainstem contusion was also noted postmortem.

Head impact, however, is not necessary for this injury to occur.

Case 2

A 16-year-old male pedestrian, 175 cm tall and weighing 66 kg was struck by a late model sedan traveling 60 km/h (35 mph). Corresponding to right bumper and anterior hood contact, there were fractures of the left tibia-fibula and the left pelvis. Hyperextension of the thoracic spine caused fracture-dislocation of the eleventh thoracic vertebra. A tear of the descending thoracic aorta was also noted. Subgaleal hemorrhage was seen over the entire scalp. The atlanto-occipital ligaments were completely disrupted (Fig. 4) and the cervicomedullary junction was transected. The cervical spine was intact.

In this case, sudden acceleration applied to the lower body and the inertia of the relatively massive head, weighing about 7 kg, caused it to snap in a whiplike manner, causing shearing of the atlanto-occipital ligaments (Fig. 5).

Case 3

A 21-year-old male cyclist suffered a similar fate when hit from behind by a late model car going an estimated 70 km/h (40 mph). The high cervical cord was transected. The remaining cervical spine was intact.

Atlas

Case 4

A 58-year-old male was one of four unbelted rear passengers in a car traveling 50 km/h (30 mph). It slid sideways, the right side hitting a highway pole. The subject, who was on the right side, impacted the right door with his torso sustaining chest and pelvic trauma. Lacerations and contusions of the right upper forehead and scalp were consistent with these areas hitting the right upper door sill and roof. On hospital admission, he was conscious without neurological deficit. Despite radiological evidence of C1 right anterior and posterior arch fractures, he remained clinically stable. These fractures were managed conservatively with no neurologic sequelae.

A sudden direct load to the vertex of the head compresses the spinal column. The occipital

FIG. 4—*Radiograph of atlanto-occipital dislocation. Case 2.*

FIG. 5—*Impact of motor vehicle with pedestrian's lower body causing high-intensity shear forces at atlanto-occipital level. Case 2.*

condyles are forced down in wedge-like fashion, into the atlas fracturing the anterior and posterior arches—that is, a Jefferson fracture (Fig. 6*a*). Bony fragments are displaced outwards, widening the spinal canal and sparing the cord (Fig. 6*b*). If differential loading occurs, as in this particular case, then a unilateral fracture results.

Axis

During extension, the lateral masses and relatively weak pedicles are the point of greatest leverage between the "cervico-cranium" (skull, atlas, dens, and body of axis) and the relatively fixed lower cervical spine to which the neural arch of the axis is anchored by the inferior facets, bifid spinous process and strong nuchal muscles [*2,3*]. If extension is severe, then a symmetrical break may occur across the lateral masses, pedicles and even laminae. The posterior area of the vertebral body may be involved, but the odontoid process remains intact. Individual cases of this "hangman's" fracture were recognized as occurring during motor vehicle collisions [*4-6*] in the 1950s and early 1960s. Subsequently Schneider et al. [*2*] reviewed eight cases. In our recent study [*7*], this fracture was associated with two different presentations.

Judicial hanging involves a rapidly moving individual falling from a height, "the long drop" (about 2 m [6 ft], depending on the victim's weight). The body is suddenly restrained by a knot under the chin or around the neck. If properly done using a submental knot, violent extension forces will cause the classical fracture [*8*]. In addition, distraction causes displacement of the body of C2 and intact C1 posteriorly in relation to the rest of the cervical spine (Fig. 7), including the fixed neural arch of the axis. Consequently, there is either lethal or neurologically significant injury to the high cervical spinal cord.

Two such cases of hangman's fracture in the setting of motor vehicle collision were investigated.

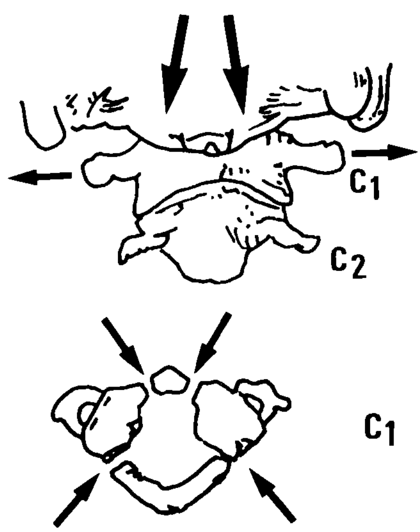

FIG. 6—*Jefferson fracture:* (top) *axial loading of cranium forcing occipital condyles into atlas;* (bottom) *consequent fractures of anterior and posterior arches with splaying of fragments.*

FIG. 7—*Classical hangman's fracture. Extension and distraction of body of axis and intact atlas with fixation of neural arch of axis to lower cervical spine.*

Case 5

A 36-year-old woman was the right front passenger in a car going 90 km/h (55 mph). Its left side hit the rear of a stationary truck semi-tractor-trailer. The case vehicle sustained broad crush across the left front and center with penetration of 35 cm (14 in.). The woman, who was wearing a lap and torso belt, died instantly. She sustained a hangman's fracture and trauma to the adjacent cord from sudden forceful extension and distraction of the cervical spine following chin contact with the instrument panel. Analysis of the restraint system indicated about 20 cm (8 in.) of slack. The shoulder harness may have slipped off her shoulder or was placed in the axilla for comfort and convenience.

Case 6

A 34-year-old woman was the right front passenger in a car traveling 80 km/h (50 mph). The car went off the road, the front end hitting a culvert, which partially arrested the vehicle's forward motion. It became airborne for 9 m (30 ft) and landed on its roof. The subject was wearing a lap and torso belt with the bucket seat fully reclined. She was found tangled in the seat-belt webbing suspended above the underlying roof. She was briefly unconscious. Numbness and tingling in both shoulders, neck and shoulder pain, and decreased strength and numbness in the legs were noted. X-rays (Fig. 8) showed fractures of the axial pedicles. Halo traction improved leg symptoms, but right arm and hand weakness persisted for months.

Although fatal or severely debilitating hangman's fracture in motor vehicle collisions has been described by various authors [*9,10*], most do not have serious acute or chronic neurologic sequelae [*3*].

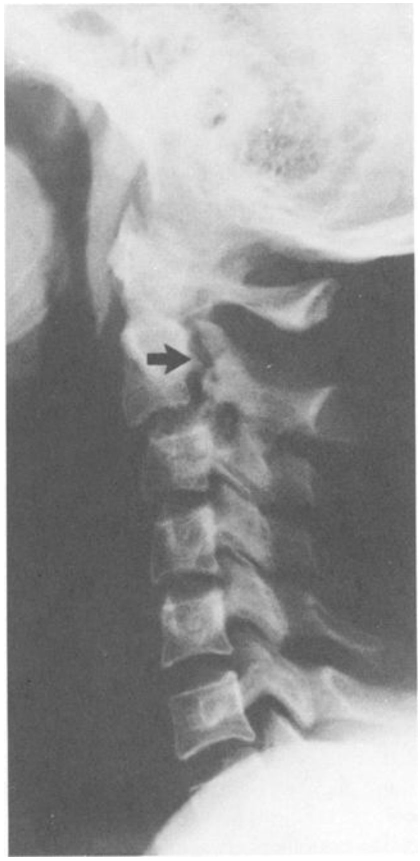

FIG. 8—*Radiograph of axis pedicle fracture, Case 6.*

Case 7

A 34-year-old woman, an unbelted right front passenger, sustained bruises of her forehead after hitting the upper windshield and sunvisor of a car which went out of control at 100 km/h (60 mph) and hit a barrier. X-ray showed fracture of the pedicles of the axis. She was asymptomatic and recovered uneventfully with a cervical collar.

Case 8

A 62-year-old man, an unbelted right front passenger, was in a car which went out of control at 80 km/h (50 mph). Its right front hit a ditch, rolled, and came to rest on its wheels. He had a closed head injury and remained comatose. Admission X-rays showed pedicle fractures of the axis with anterior displacement of the C2 body and C3. No clinical signs were caused by this injury. He died of sepsis one month later. Autopsy revealed no spinal cord damage.

In a collision, an unrestrained vehicle occupant is projected forward to hit a part of the interior with his head. Vulnerability to injury is enhanced by "ducking" or slightly extending the neck before collision [*11*]. At collision, the neck is hyperextended and impact forces on the head cause loading or compression along the cervical spine. The aftercoming rest of the body exerts inertial forces (Fig. 9). The leverage point, that is, lateral masses and pedicles of the axis, is broken; however, there are no distractive forces (Fig. 10). Bone fragments are not dislocated, but actually separate and widen the spinal canal. As a result, neurologic symptoms tend to be minimal and reversible with conservative treatment. Because the mechanism and presentation of motor-vehicle-related axis fractures differs usually from classical hanging, the term "traumatic spondylolisthesis of the axis" has been proposed [*4*]. Some authors [*12*] have favored flexion and traction of the cervical spine as causing the hangman's fracture.

Conclusion

Although cranial trauma caused the atlas (Jefferson) and axis ("hangman's") fractures in our cases of motor vehicle collision, head contact was not necessary to disrupt atlanto-occipital ligaments, a situation given little attention in the literature. This injury was invariably fatal, but fractures of the first and second cervical vertebra did not necessarily cause death or serious neurologic consequences. In the case of the Jefferson fracture, bony fragments splayed apart, widened the spinal canal, and did not injure the cord. Similarly, this happened in the more typical cases of motor-vehicle-related hangman's fracture, that is, caused by hyperextension and loading of the cervical spine. The mechanism of hyperextension and distraction causing clinically significant hangman's fracture is less common in automobile crashes.

Other than avoiding collision in cases of atlanto-occipital dislocation, the various upper cervical spine injuries described could be prevented by avoiding or modifying head contact with the interior of the vehicle. This could be achieved by proper use of restraint systems and improvements in displacement patterns of vehicle frontal structures. Passengers should not use fully reclined bucket seats during vehicle motion to prevent submarining under belts.

The pathologist examining a high cervical injury as a result of motor vehicle collision should not only integrate postmortem findings with accident investigation reports and clinical information (including X-ray examination), if applicable, to elucidate injury biomechanics, but also realize that not all high cervical spine injuries are fatal or even life-threatening.

FIG. 9—*Mechanism of hangman's fracture in motor-vehicle frontal impact. Extension, axial loading, and shear of upper cervical spine.*

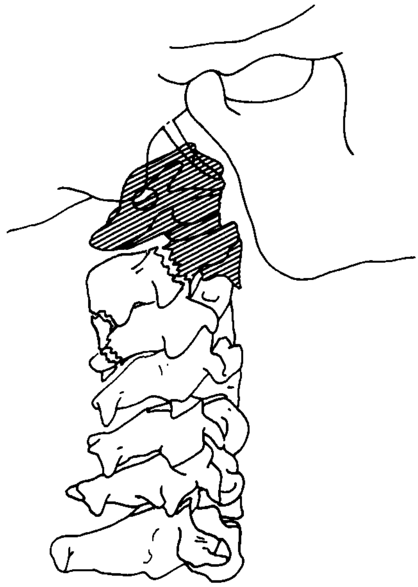

FIG. 10—*Motor-vehicle-related hangman's fracture (traumatic spondylolisthesis). Extension and axial loading do not lead to significant dislocation.*

Acknowledgments

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Erratum

In the article "Upper Cervical Trauma in Motor Vehicle Collisions," in the March 1989 issue of the *Journal,* Ref. 1 should be Vol. 11 not Vol. 2 as originally printed. The year of publication of this reference was 1984.