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Original Article

Unilateral atlanto-axial fractures in near side impact collisions: An under recognized entity in cervical trauma

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Abstract

Objective: Nearside impact collisions presenting with lateral mass fractures of atlanto-axial vertebrae contralateral to the impact site represents a rare fracture pattern that does not correlate with previously described injury mechanism. We describe our clinical experience with such fractures and propose a novel description of biomechanical forces involved in this unique injury pattern. The findings serve to alert clinicians to potentially serious consequences of associated unrecognized and untreated vertebral artery injury. **Material and Methods**: In addition to describing our clinical experience with three of these fractures, a review of Crash Injury Research and Engineering Network (CIREN) database was conducted to further characterize such fractures. A descriptive analysis of three recent lateral mass fractures of the atlanto-axial segment is coupled with a review of the CIREN database. A total of 4047 collisions were screened for unilateral fractures of atlas or axis. Information was screened for side of impact and data regarding impact velocity, occupant injuries and use of restraints. **Results:** Following screening of unilateral fractures of atlas and axis for direct side impacts, 41 fractures were identified. Cross referencing these cases for occurrence contralateral to side of impact identified four such fractures. Including our recent clinical experience, seven injuries were identified: Five C1 and two C2 fractures. Velocity ranged from 14 to 43 km/h. Two associated vertebral artery injuries were identified. **Conclusions:** Complexity of the atlanto-axial complex is responsible for a sequence of events that define load application in side impacts. This study demonstrates the vulnerability of vertebral artery to injury under unique translational forces and supports the use or routine screening for vascular injury. Diminished sensitivity of plain radiography in identifying these injuries suggests that computerized tomography should be used in all patients wherein a similar pattern of injury is suspected.

Key words: Atlano-axial fractures, C1 fractures, C2 fractures, side impact collisions

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INTRODUCTION

Numerous reports of atlanto-axial injuries have described a variety of fracture patterns and proposed certain mechanisms responsible for their creation.[1-5] Recently, the authors have encountered three patients involved in automobile collisions who demonstrated unilateral isolated fractures of the axis or atlas lateral mass arising from forces that do not correlate with these previously described mechanisms of injury. In each instance, the injured subject was a belted occupant involved in a near-side lateral impact and presented

with lateral mass fractures contralateral to side of impact. The fractures were not visualized on plain radiographs and required computerized tomography (CT) scanning for identification. In addition, a review of the Crash Injury Research and Engineering Network (CIREN) database was conducted to further characterize such atlanto-axial fractures incurred from the near side impacts.

REPORTED CASES

Patient 1

An 87-year-old female was the restrained (three-point system) driver of a vehicle involved in a lateral collision to the driver's side door. No airbag deployment occurred. On arrival to the emergency facility, she reported left shoulder and cervical pain. She was neurologically intact and exhibited widespread contusions on the left forehead and periorbital areas.

A radiographic survey (anterior/posterior, lateral, and open mouth odontoid X-ray films) demonstrated no fracture. A CT scan of the cervical spine revealed a discrete fracture through the right C2 lateral mass extending into the foramen transversarium with minimal lateral avulsion of the fragment [Figure 1a]. A CT angiogram of the neck demonstrated normal vertebral arteries. Her fracture was managed with an 8-week period of immobilization in a rigid cervical orthosis.

Patient 2

A 31-year-old female was the restrained (three-point belt system) driver of a vehicle involved in a direct collision to the driver's side door. Upon arrival to the hospital she described no loss of consciousness and cited positive frontal airbag deployment during the collision. She was neurologically intact and was noted to have a small area of soft tissue swelling overlying the left clavicle, but no facial edema or abrasions. While in the emergency facility, she described two brief episodes of self-resolving vertigo.

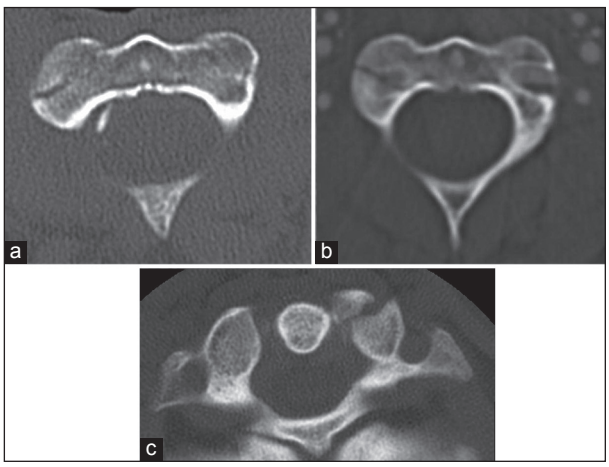

Figure 1: (a) Axial computerized tomography (CT) of c-spine shows a right C2 lateral mass fracture without significant fragment evolution. (b) CT angiogram of the neck shows a right C2 lateral mass fracture with extension across the associated foramen transversarium. (c) CT of c-spine shows a left C1 lateral mass fracture with modest fracture displacement

While plain radiographs of the cervical spine were negative for fracture, CT scan of the cervical spine showed a linear fracture of the right C2 lateral mass with extension into foramen transversarium [Figure 1b]. CT angiogram showed narrowing of her right vertebral artery with an associated intimal irregularity. For treatment of her fracture, she was maintained in a rigid orthosis for 6 weeks. Her vertebral artery injury was managed with intravenous heparin, which was later transitioned to oral Coumadin prior to discharge. At 3-months follow-up, she was without subjective complaints and her arterial injury was no longer visualized on repeat CT angiography.

Patient 3

A 50-year-old female was the restrained (two-point belt system) right rear seat passenger in a vehicle that incurred direct side impact to the right front and rear door areas resulting in approximately 37 cm of occupant compartment intrusion. On arrival to the emergency department, she denied any loss of consciousness, but complained of axial neck and back pain. Examination demonstrated a 7 cm laceration extending from the superior lateral right orbit to the scalp, 3 cm laceration of the right upper extremity above the elbow, ecchymosis of the right periorbital area, and contusions of the right posterior thoracic region. Chest radiograph showed multiple fractures of the right posterior lateral ribs, and CT scan of the abdomen demonstrated a laceration of the liver. She was neurologically intact. Cervical spine radiographs were unremarkable for evidence of traumatic injuries, but cervical CT scan demonstrated a fracture of the C1 lateral mass with 2 mm displacement [Figure 1c]. CT angiogram was negative for vascular injury. The cervical fracture was managed with a rigid orthosis. At 2-month follow-up, lateral flexion and extension radiographs of the cervical spine demonstrated an increase in the atlanto-odontoid (AO) interval with flexion to 4 mm. This widening of the predental space was suggestive of possible attenuation of the transverse atlantal ligament. Follow-up magnetic resonance imaging, however, showed no definitive progression of possible ligamentous injury with the AO interval remaining stable.

Crash Injury Research and Engineering Network analysis

The CIREN consists of a catalogue of multiple discrete data fields concerning motor vehicle crashes.[6] Data sets date from 1996 to present and include analysis of crash kinematics and medical injury profiles. At the time of this review, there were a total of 4047 cases within the database. The database was screen by two neurosurgeons for unilateral fractures of the atlas (C1) or axis (C2) secondary to side directed impacts. This search revealed 41 of such fractures. Cross referencing these cases for occurrence contralateral to the side of impact identified only four fractures. Although the analysis was directed at identifying isolated C1 and C2 lateral mass fractures, the presence of transverse process (TP) fractures distal and in opposition to

the lateral mass were noted in two of the CIREN subjects. Of note, all four of these cases exhibited fractures confined to the C1 vertebra and one case included concurrent vertebral artery injury. This latter case was also notable as the singular instance, wherein side airbags were utilized. Despite the deployment of frontal, roof side-rail curtain, and seatback mounted torso airbags following a collision at an unknown speed, a contralateral fracture to the C1 TP and extensive systemic injuries were incurred. Among those CIREN cases where estimated speed of impact was known, velocity ranged from 14 to 43 km/h. The present series, therefore, is a combined analysis of the CIREN data and present clinical experiences [Table 1].

DISCUSSION

Gehweiler *et al.* reviewed 400 atlas fractures and noted that isolated lateral mass fractures were rare events, occurring in three patients. They proposed that these injuries were the result of asymmetric axial loads.[3] Young *et al.* supported the unusual occurrence of this fracture pattern finding only one such event in reviewing 112 C1 fractures.[7] Unilateral fractures of the axis are also unusual events, but their presence are cited more frequently than their counterpart in the atlas.[2,8-11]

Isolated fractures of the adjoining bony components to the lateral masses of the atlanto-axial complex are also uncommon findings.[1,2] Inaoka *et al.* noted the exceedingly rare incidence of a singular break in the atlas ring in citing two cases. One of these cases was significant for extension of the fracture in to the ipsilateral lateral mass.[12] Although Gehweiler *et al.* identified no isolated fractures of the TP of the atlanto-axial complex, this study recognized two lateral mass fractures with extension into the foramen transversarium and the CIREN analysis identified two isolated TP fractures [Table 1].

The present report, therefore, describes three isolated lateral mass fractures (one atlas and two axis) presenting within a 2 month period and associated with near-side vehicle collisions. This chronologic pattern suggests that such injuries may be more common than previously recognized. Plain radiographs failed to diagnose these injuries, which were only identifiable on CT scanning. This limitation in the diagnostic value of plain radiographs may offer some additional explanation for the limited reports of such injuries and supports the development of routine diagnostic protocols utilizing CT evaluation in all cases where atlanto-axial fractures are suspected.

In all cases within the present report, the atlanto-axial complex was subject to similar occupant kinematics and pattern of load application. The subjects incurred initial movement toward the side of impact resulting in contact with the structures of the occupant compartment.[13] Impact of the lateral and frontal calvarium will cause a reversal of the head-neck complex motion with lateral bending toward the side contralateral to the impact [Figure 2]. The complexity of the atlanto-axial complex is responsible for a sequence of events that define load application in these impacts. Motion of the atlanto-axial complex is considerably restricted by the alar ligaments which are relatively inelastic.[14] These ligaments function to limit axial rotation and are coupled with the transverse ligament which may also provide a constraining component in this differential motion. The corresponding capsular ligaments at this level are loose and allow significant lateral motion. Therefore, the capsular ligaments will allow potentially excessive lateral bending while the alar ligaments serve to supply the necessary centripetal force to counter the axis in forced rotation.[15] In these near side impacts, the atlanto-axial complex contralateral the side of impact may be

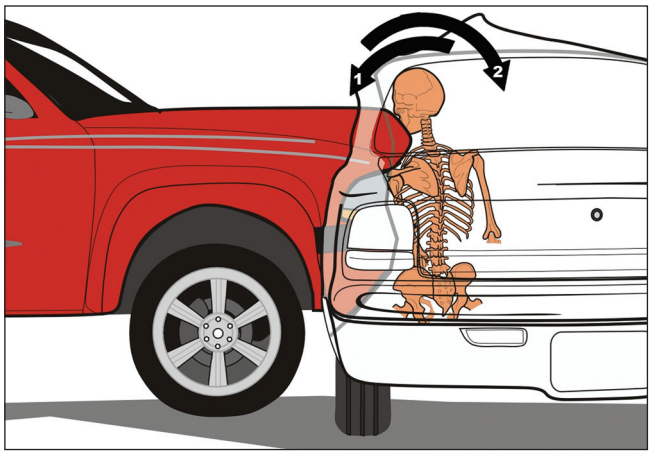

Figure 2: A schematic illustration portrays an occupant subject to direct side-impact with initial movement towards the side of impact followed by reversal of the head-neck complex motion with lateral bending toward the side contralateral to the impact

Table 1: Combined analysis of the CIREN data and present clinical experiences

Age	Sex	Level	Structure	Side of Impact	Speed	Injuries
41	F	C1	LM	Passenger	43 km/h	Acetabular fracture, pulmonary contusion, splenic laceration, SAH, SDH
40	M	C1	TVP	Driver	14 km/h	Mandible, humerus, and clavicle fractures
81	F	C1	LM	Driver	19 km/h	Rib fractures
56	M	C1	TVP	Driver	Unknown	SAH, SDH, splenic laceration, pulmonary contusion, vertebral artery occlusion
87	F	C2	LM	Driver	Unknown	none
31	F	C2	LM	Driver	64 km/h	Vertebral artery dissection
50	F	C1	LM	Passenger	Unknown	Rib fractures

LM = lateral mass, Km/h = kilometers per hour; TVP = transverse process; SAH = subarachnoid hemorrhage; SDH = subdural hemorrhage

exposed to adverse compression loads causing the lateral masses and TPs to incur this unique fracture pattern as well as potential injury to the corresponding vertebral artery.

Numerous articles have documented that trauma to the posterior elements of the cervical spine will have a risk of associated blunt vertebral artery injury (BVAI). Evidence of facet, lateral mass, TP, or C1-C3 fractures are noticeably relevant to such vascular trauma.[16-19] Ringer *et al.*, proposed that energy sufficient to produce such injuries would also suffice to cause vertebral artery injury. These authors noted that in a series of 114 patients with cervical fractures, 30.7% showed angiographic evidence of blunt cerebrovascular injury.[19] Miller *et al.*, reviewed 109 angiographic studies in patients cervical fractures and found 36 patients (33%) with vertebral artery injury. Twenty-eight of these patients had foramen transversarium involvement. Of the remaining eight patients, five individuals exhibited facet subluxation.[18] Vives *et al.* authored a review of the natural history, incidence, diagnosis, and management option for vertebral artery injury in the setting of blunt trauma to the cervical spine. This review supported the contention that BVAI is a fairly common occurrence in the cervical spine trauma with incidence ranging from 20% to 26% and potential neurologic sequele from 0.7% to 24%, respectively.[20] Stein *et al.*, in evaluating blunt cerebrovascular injuries, noted a 26% rate of stroke in untreated patients compared with 4% in treated patients.[21] While these finding as well as other published reports support the general argument that therapeutic intervention mitigates the risk of stroke as well as well as decreases the severity of such events, no such consensus exists regarding the most efficacious therapy. Anticoagulation, antiplatelet, and interventional have all been applied with varying levels of success. In this regards, the efficacious results with aspirin have innumerous advocates.[22] These findings support that both the fracture pattern described above and facet dislocations are a strong indicator of potential BVAI. As CT angiography has shown a 99% accuracy compared with conventional angiography in the identification of such injuries, these studies are likely responsible for the recent marked increase in detection of BVAI and should be used in the screening for all patients with this pattern of atlanto-axial injury.[17] These considerations emphasize that the recognition of a potential BVAI is critical to the implementation of a relatively safe, simple, and effective protective therapy.

During the CIREN review this rare fracture pattern was identified in a case wherein side impact airbags were deployed. It has been shown that side airbag deployment significantly reduces neck/cervical injury severity in near-sided impact collisions.[23] However, it is unknown whether the increasing utilization of side airbags may be a causative factor in the formation of uncommon fractures secondary to occupant-compartment contact or may change the relative frequency of cervical fractures by providing disproportionate protection across the known range of injuries. Given the increasing utilization of side airbags in modern automobile production, an additional biomechanical investigation, using a different epidemiological database such as the National Automotive Sampling System, would be needed to better understand the full implication of side airbag deployment in cervical trauma.

Analysis of human cervical spine uncovertebral joint anatomy has demonstrated that larger and more well developed joints are found at the mid and lower cervical levels.[24] The paucity of well-developed articulations at the atlanto-axial level may modify the coupled kinematics of the cervical spine in lateral impact injury significantly. This variation may diminish load sharing in a fashion that contributes to the pattern of injury noted in this series. Understanding this complex boney anatomy in combination with the unique arrangement of muscular and ligamentous attachments at these levels is key to explaining these rare fractures observed in the C1 and C2 vertebrae under significant translational forces.

CONCLUSIONS

The complexity of the atlanto-axial complex is responsible for a sequence of events that define load application in these side impacts. This study demonstrates the vulnerability of the vertebral artery to injury under these unique translational forces and supports the use or routine screening for vascular injury. In addition, the diminished sensitivity of plain radiography in identifying these injuries suggests that CT should be utilized in all patients, wherein a similar pattern of injury is suspected.

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