CT and MRI-based Diagnosis of Craniocervical Dislocations: The Role of the Occipitoatlantal Ligament

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Published online: 27 October 2011
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Abstract

Background Craniocervical dislocations are rare, potentially devastating injuries. A diagnosis of craniocervical dislocations may be delayed as a result of their low incidence and paucity of diagnostic criteria based on CT and MRI. Delay in diagnosis may contribute to neurological injury from secondary displacement resulting from instability.

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All ICMJE Conflict of Interest Forms for authors and *Clinical Orthopaedics and Related Research* editors and board members are on file with the publication and can be viewed on request. Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that a waiver of informed consent was obtained by the institutional review board prior to beginning work on this study.

This work was performed at Thomas Jefferson University, Philadelphia, PA, USA.

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The purpose of this study was to define CT and MRI-based diagnostic criteria for craniocervical dislocations to facilitate early injury recognition and stabilization.

Questions/purposes Using CT and MRI, we (1) described the bony articular displacements characterize craniocervical injuries; (2) described the ligamentous injuries that characterize craniocervical injuries; and (3) determined whether neurologic injuries were associated with bony or ligamentous injury.

Methods Using a prospectively collected spinal cord injury database, we identified 18 patients with acute, traumatic occipitocervical injuries. We reviewed CT scans and MR images to document the height of the occipitoatlantal and atlantoaxial joints and integrity of craniocervical ligaments. Medical records were reviewed for neurological status. The primary measurements were number of patients with articular displacement, location of bony displacement, and number of patients with ligamentous injury.

Results Thirteen of 18 patients had displacement outside the normal range. Six patients demonstrated displacement of both occipitoatlantal and atlantoaxial joints, whereas five patients presented with displacement through the atlantoaxial joints only. Two patients had an abnormal basion-dental interval only. Of 17 patients with MR images, the cruciate ligament was injured in 11 patients, indeterminate in four, and intact in two. All five patients with occipitoatlantal articular displacement had injury to the occipitoatlantal capsule. No patient had occipitoatlantal capsular injury without occipitoatlantal articular displacement. Three cases of complete spinal cord injury were found after occipitoatlantal-atlantoaxial dislocations. Three patients with occipitoatlantal-atlantoaxial dislocations were neurologically intact. The five patients with atlantoaxial dislocations and patients without displacement or ligamentous injury were neurologically intact. Five patients

had cruciate ligament rupture or indeterminate injury but no joint diastasis.

Conclusions The occipitoatlantal joint capsules stabilize the occipitoatlantal joint; disruption of the occipitoatlantal capsule may suggest the presence of instability. Based on these findings, we identified two distinct injury patterns: isolated atlantoaxial injuries (Type I) and combined occipitoatlantal-atlantoaxial injuries (Type II). Occipitoatlantal joint capsule integrity differentiated these subsets and Type II injuries had a higher percentage of complete spinal cord injuries on presentation.

Introduction

Craniocervical dissociative injuries are major injuries with potentially devastating clinical consequences. These injuries are present in 6% to 20% of fatal high-speed blunt trauma accidents [12]. Timely diagnosis and stabilization of craniocervical injuries is paramount because there is a risk of neurologic injury from secondary displacement if the injury is initially missed on presentation [3].

Initial diagnostic criteria for craniocervical dissociative injuries have focused on direction and magnitude of bony displacement at the time of imaging. Earlier proposed criteria focused on midline structures such as the dens, basion, and opisthon [7, 11, 12] because these were most readily visible on radiographs, the predominant trauma screening study at the time. Subsequent studies [4, 18, 24] have determined the normative height of the occipitocervical joints on CT scan and implied these may be important in designing diagnostic criteria for craniocervical injuries. Specifically, the upper limit of normal for anterior and posterior occipitoatlantal joint heights is 1.3 mm, whereas the lateral atlantoaxial joint height should not exceed 1.6 mm and the basion-dental interval should be less than 9.4 mm on CT sagittal and coronal reconstructions [22]. Diastasis of the occipitoatlantal and atlantoaxial joints may be a specific sign for craniocervical injury [4, 18, 24]. However, there are several limitations to CT as a screening modality for craniocervical injuries. Harris [13] reported studies of the articular relationships are susceptible to false-negative errors as a result of patient positioning; it is possible to have normal radiographs or even a normal CT scan in the presence of ligamentous instability. Conversely, mistakenly large CT measurements may occur if the plane and position of measurement are not orthogonal to the joint surface, resulting in false-positive errors [22].

MRI provides precise anatomic information about soft tissue injury. The cruciate ligament is considered the predominant stabilizer of the craniocervical articulation [19, 31, 32]. Previous reports have identified MRI disruption of the cruciate ligaments and effusion within the occipitocervical

joints as signs of craniocervical dissociative injuries [3, 5, 14]. However, the specific patterns of ligamentous injury have not been clearly detailed.

Improved diagnostic criteria for occipitocervical instability may prevent secondary neurological injury resulting from a delay in diagnosis. Specifically, a patient with an unstable spine resulting from an occipitocervical injury would be at risk for further subluxation during intubation, positioning, or bed transfers in the hospital. The goal of diagnosis of occipitocervical instability is to identify patients who would benefit from stabilization of pathologic subluxation and prevent secondary neurologic damage resulting from late displacement. Previous classifications [3, 14, 27] have not integrated bony displacement, ligamentous stability, and neurologic injury into a simple algorithm to improve diagnosis and management of occipitocervical instability.

We therefore (1) described the bony displacements that characterize craniocervical injuries; (2) described the ligamentous injuries that characterize craniocervical injuries; and (3) determined whether neurologic injuries were associated with bony or ligamentous injury.

Patients and Methods

We retrospectively identified 23 patients with traumatic craniocervical dislocation from a prospectively collected regional spinal cord injury center database of 4519 patients from 2005 to 2010. A STROBE table was completed for this investigation and the text organized according to the STROBE guidelines [26]. The database was specifically queried for the terms “craniocervical dislocation”, “occipital-atlanto dislocation”, “occipito-atlanto dissociation”, “atlanto-axial dislocation”, “atlanto-axial dissociation”, “craniocervical injury”, “occiput-C1 dislocation”, “occiput-C1 dissociation”, “C1-C2 dislocation”, “C1-C2 dissociation”. The records of all patients with traumatic C1 injuries were reviewed for possible injuries. We excluded patients with atraumatic etiology of craniocervical dislocation such as secondary to postsurgical, infectious, or neoplastic instability and patients with rheumatic, degenerative, or congenital instability of the atlantoaxial joints. Of the 23 patients, we excluded five because CT scans or MR images were not available, leaving 18 patients for study. We reviewed hospital records, associated injuries, and in-hospital followup for all patients (Table 1). At our institution, patients with spinal cord injury are evaluated independently by three clinical services (orthopaedic surgery, neurosurgery, and physiatry) who then review the case at a multidisciplinary conference to determine a consensus diagnosis and treatment plan. The neurologic status of all patients was classified using the

Table 1. Demographic characteristics of the patient population

Patient number	Age (years)	Gender	Mechanism	Associated injuries
1	66	M	MCA	Type II odontoid fracture
2	40	M	MVA	Open ulna fracture, abdominal wound
3	49	M	MCA	Open calcaneus fracture
4	50	M	Auto-pedestrian	
5	27	M	MVA	Pneumothorax
6	46	M	Auto-pedestrian	Fibula fracture
7	46	F	MVA	Subdural hematomas, pneumothoraces, fibula fracture, clavicle fracture, mandible fracture
8	26	M	MVA	Type III odontoid fracture, clavicle fracture
9	25	M	MVA	Cardiac arrest, sigmoid colon injury, renal hematoma, open humerus fracture, acetabulum fracture, traumatic brain injury
10	59	F	Fall	None
11	65	M	Fall	Hangman's fracture, traumatic brain injury
12	83	M	MVA	Rib fractures, abdominal organ injury, odontoid fracture 100% translated
13	41	M	MVA	Open femur fracture, distal radius fracture, rib fractures, pneumothorax
14	52	M	Fall	Pneumothorax, acetabulum fracture, hemothorax
15	79	M	MVA	Odontoid fracture, humerus fracture
16	68	M	MVA	Odontoid fracture, occipital condyle fracture, respiratory distress in emergency department
17	18	M	Sports accident	Transient quadriplegia
18	47	F	MVA	T4,T5 fractures, multiple rib fractures, hemothorax, left distal humerus fracture, left open ankle fracture, liver laceration, pancreatic contusion

M = male; F = female; MCA = motorcycle accident; MVA = motor vehicle accident.

Table 2. Normative measurements of the craniocervical junction on CT [22]

Joint	Orientation	Upper limit of normal measurement
Occiput-C1 anterior and posterior aspect	Midparasagittal plane measurement of joint height	1.3 mm
Lateral C1-C2 joint height	Midcoronal plane measurement of lateral joint height	1.6 mm
Basion dental interval	Midsagittal plane	9.4 mm

American Spinal Injury Association (ASIA) Scale [1]. We had a priori Institutional Review Board approval.

We documented demographic criteria and mechanism of the injuries. CT scans of the cervical spine for the patients were analyzed according to previously published criteria (Table 2). All patients were diagnosed on presentation to the emergency department; there were no late diagnoses after admission. Using the available PACS software (Phillips Isite, Andover, MA, USA), one of us (KER) measured the anterior height of the occipitoatlantal joints from the anterior aspect of the occipital condyle to the anterior aspect of the C1 lateral mass. The posterior height

of the occipitoatlantal joints was measured from the posterior aspect of the occipital condyle to the posterior aspect of the C1 lateral mass. We measured the anterior and posterior occipitoatlantal joint height on the left and right sides on a parasagittal CT reconstruction bisecting the C1 lateral mass. The lateral atlantoaxial joint height was measured from the lateral aspect of the C1 lateral mass to the lateral aspect of the C2 superior articular facet. We measured the lateral atlantoaxial joint height on a coronal reconstruction bisecting the C1 lateral mass. We measured the basion-dental interval on a midline sagittal CT reconstruction along a distance from the basion to the tip of the dens. The measurements were compared with values of the upper limit of a normative trauma population on CT scan [22]. The 99% confidence interval of normal anterior and posterior occipitoatlantal joint heights is less than 1.3 mm, lateral atlantoaxial joint height is less than 1.6 mm, and basion-dental interval is less than 9.4 mm [22]. Measurement parameters for CT described in this investigation have been previously described in a study [22] that demonstrated minimal interobserver variability.

One of us (KR) analyzed MR images for the 17 patients who had an available MRI. T1-weighted, T2-weighted, fat saturation/proton density, and short tau inversion recovery (STIR) images were evaluated. On a midsagittal view, we graded the status of the cruciate ligament as intact, disrupted, or indeterminate. On a parasagittal view bisecting the C1 lateral mass, the occipitoatlantal joint was examined for congruity and capsular integrity. We identified the occipitoatlantal joint capsule as a linear structure of low signal intensity on T2 image sequences from the anterior superior aspect of the C1 lateral mass to the skull anterior

to the occipital condyle (Fig. 1). On MRI sequences in which the occipitoatlantal capsular structures could not be distinguished from the adjacent soft tissue as a result of MRI technique (STIR sequence does not distinguish soft tissue structures as clearly as other sequences), we used the presence of high joint fluid signal on T2 images in an abnormal location usually occupied by the occipitoatlantal capsule as a marker of capsular injury and lack of integrity. The presence of fluid signal within a soft tissue structure has been previously used as a diagnostic criterion for tears of the knee meniscus [15] and shoulder [16].

Results

Bony displacement was measured and reported on all patients including average occipitoatlantal, atlantoaxial, and basion-dental intervals (Table 3). Overall, 13 of 18 patients had displacement outside of the 3 SD confidence intervals of normal (Table 4). Six patients presented with displacement through both occipitoatlantal and atlantoaxial joints. No patient had an isolated occipitoatlantal dislocation (without atlantoaxial displacement). Five patients presented with displacement through the atlantoaxial joints only and demonstrated normal occiput-C1 height (Table 4). Two of these patients (Patients 6 and 14) had obvious atlantoaxial disruption but measurements were unable to be performed as a result of obliquity of the plane of coronal reconstruction. One patient (Patient 15) did not have a coronal reconstruction CT performed. Patient 4 had a baseline CT scan before the dislocation for a separate trauma 3 months before the occipitoatlantal-atlantoaxial

Fig. 1A–B (A) Parasagittal T2 MRI through the midportion of the C1 lateral mass displays low T2 signal intensity extending from the anterior aspect C1 lateral mass inserting anterior to occipital condyle. (B) This diagram represents the C1 joint capsule.

Table 3. Mean measurements*

Patient subgroup		Left OA anterior	Left OA posterior	Right OA anterior	Right OA posterior	Left AA	Right AA	Basion-dental interval	Mean OA displacement	Mean AA displacement
Overall population	Mean	3.5	3.4	3.5	3.2	4.1	3.1	11.2	3.4	3.6
	SD	6.0	4.9	5.4	4.3	6.2	3.6	5.1	5.2	4.9
Patients with AA Dislocation (Type I)	Mean	0.8	1.0	0.7	0.8	5.0	3.6	9.5	0.8	4.3
	SD	0.2	0.3	0.2	0.2	7.7	4.5	3.8	0.2	6.1
Patients with OA-AA dislocation (Type II)	Mean	8.7	8.2	9.0	7.9	3.1	2.5	16.0	8.4	2.8
	SD	8.6	6.3	6.8	4.7	1.8	0.7	3.4	6.6	1.3

* All distances are in millimeters; OA = occipitoatlantal; AA = atlantoaxial.

dislocation (Fig. 2A–C). CT scanning performed after dislocation injury confirms the joint subluxation associated with occipitoatlantal injuries (Fig. 2D–F). The preinjury and postinjury measurements of the occipitoatlantal and atlantoaxial joints (Table 5) confirm that the dislocation results in subluxation of the occipitoatlantal joints (preinjury mean, 0.5 mm; postinjury mean, 20 mm), basion-dental interval (preinjury 5.6 mm, postinjury 22 mm), and lateral atlantoaxial articulation (preinjury 0.75 mm, postinjury 2.4 mm). All bony measurements exceeded the threshold measurement of normal on the postinjury CT scan. Pre- and postreduction measurements on Patient 5, who underwent bedside awake closed reduction in a halo, were reported (Table 6). Before the reduction, all of the measurements were abnormal. After closed reduction, four of the seven measurements were within the range of normal. Twelve patients had abnormal basion-dental interval (BDI). Seven of these patients with abnormal BDI had no major articular displacement, although two of these individuals had abnormal BDI. Two of the five individuals with an odontoid fracture presented with major AP odontoid fracture displacement (Fig. 3A, prereduction) that was subsequently reduced (Fig. 3B).

Of the 17 patients with MRIs, five patients had injury to the occipitoatlantal joint capsule. These patients also had articular displacement of the occipitoatlantal joint. Eleven had rupture of the cruciate ligament (Fig. 4A–B), four patients were considered indeterminate (Fig. 4C), and two patients had intact cruciate ligaments. All patients with occipitoatlantal-atlantoaxial joint diastasis had cruciate ligament rupture. All five patients with isolated atlantoaxial joint space diastasis had ruptured or indeterminate cruciate ligaments. Five patients had cruciate ligament rupture or indeterminate injury but no joint diastasis. Two patients had no cruciate ligament injury and no joint diastasis.

Four patients had ASIA A injuries, three had ASIA D injuries, and the remaining 11 were neurologically intact (ASIA E) at the time of injury. Three of the six patients with combined occipitoatlantal-atlantoaxial displacement presented with neurologic injuries graded as ASIA A (complete spinal cord injury). Two of the six patients with

combined occipitoatlantal-atlantoaxial displacement presented with neurologic injuries graded as ASIA E and one presented ASIA D. All of the isolated atlantoaxial dislocations were neurologically intact (ASIA E). The five patients with no displacement and cruciate ligament injury were neurologically intact (ASIA E). One of the two patients with no displacement and no ligamentous injury was neurologically intact and one had complete spinal cord injury. All patients ultimately underwent occiput to cervical fusion when medically cleared.

Discussion

Previous classifications have not integrated bony displacement, ligamentous stability, and neurologic injury into a simple algorithm to improve diagnosis and management of occipitocervical instability. We therefore (1) described the bony displacements that characterize craniocervical injuries; (2) described the ligamentous injuries that characterize craniocervical injuries; and (3) determined whether neurologic injuries were associated with bony or ligamentous injury.

Our study is subject to a number of limitations. First was the small number of patients. The small number of patients was the result of the rare incidence of these injuries and the strict diagnostic criteria for inclusion in the study. However, our center is a major spinal cord injury center with a complete, prospectively maintained database of injuries for several years. We did not include other patients with non-dislocation traumatic injuries such as displaced occipital condyle fractures or odontoid fractures to improve the homogeneity of the population. Therefore, we believe our series represents one of the largest in the literature to characterize this specific injury. This small number of patients limits our ability to perform a rigorous evaluation of the injury groups proposed in this study to eliminate confounding variables through use of analytic methods such as multivariate regression and precludes evaluation of the sensitivity and specificity of our measurement techniques in patients with craniocervical injury. Second, we would

Table 4. Measurements of occipitocervical injury patients*

Patient number	Left OA (normal < 1.3 mm)	Left OA posterior (normal < 1.3 mm)	Right OA anterior (normal < 1.3 mm)	Right OA posterior (normal < 1.3 mm)	Left AA lateral (normal < 1.6 mm)	Right AA lateral (normal < 1.6 mm)	BDI (normal < 9.3 mm)	OA capsules	AA capsules	MRI left OA capsule	MRI right OA capsule	MRI CC ligament	ASIA	Classification
1	0.6	0.9	0.6	0.8	2.5*	1.5	12.6*	Intact	Disrupted	Intact	Intact	Indeterminate	E	I
2	0.8	0.9	0.8	0.6	5.5*	2.7*	16.5*	Intact	Disrupted	Intact	Intact	Ruptured	D	I
3	2.5*	6.9*	1.6*	6.9*	5.8*	1.8*	15.5*	Disrupted	Disrupted	Ruptured	Ruptured	Ruptured	A	II
4	21.8*	19.9*	19.1*	15.4*	1.8*	3*	22.1*	Disrupted	Disrupted	N/A	N/A	N/A	A	II
5	0.9	5.3*	8.6*	10.5*	2.2*	3.2*	15.3*	Disrupted	Disrupted	Ruptured	Ruptured	Ruptured	D	II
6	1.1	1.2	1.6*	1.8*	N/A	N/A	12.2*	Disrupted	Disrupted	Ruptured	Ruptured	Ruptured	E	II
7	0.8	1.3	0.6	1.1	3.4*	2.6*	11.6*	Intact	Disrupted	Intact	Intact	Indeterminate	E	I
8	0.5	0.8	0.3	0.5	4.7*	5.5*	5.9	Intact	Disrupted	Intact	Intact	Ruptured	D	I
9	12.9*	8.7*	13.4*	8.0*	2.5*	2.1*	13.7*	Disrupted	Disrupted	Ruptured	Ruptured	Ruptured	A	II
10	1.3	0.5	0.6	0.7	1.0	1.1	4.2	Intact	Intact	Intact	Intact	Ruptured	E	I
11	1.1	0.8	1.0	0.9	0.8	0.9	3.3	Intact	Intact	Intact	Intact	Intact	A	N/A
12	0.9	0.7	0.8	0.6	1.4	1.3	6.8	Intact	Intact	Intact	Intact	Indeterminate	E	I
13	0.7	1.1	0.7	1.3	2.3*	2.1*	11.8*	Intact	Disrupted	Intact	Intact	Ruptured	E	I
14	13.2*	7.1*	9.4*	4.5*	N/A	N/A	17.2*	Disrupted	Disrupted	Ruptured	Ruptured	Ruptured	E	II
15	0.8	1.3	0.9	0.9	N/A	N/A	10.1*	Intact	N/A	Intact	Intact	Ruptured	E	I
16	0.8	1.1	0.9	1.0	0.7	0.9	5.6	Intact	Intact	Intact	Intact	Indeterminate	E	I
17	1.3	0.9	1.2	1.1	N/A	N/A	7.4	Intact	Intact	Intact	Intact	Intact	E	N/A
18	0.6	0.9	0.6	0.8	0.8	1.2	10.2*	Intact	Intact	Intact	Intact	Ruptured	E	I

* All distances are in millimeters; upper confidence interval of normal is reported in Radcliff et al. [22]; OA = occipitoatlantal; AA = atlantoaxial; BDI = basion-dental interval; CC = craniocervical; ASIA = American Spinal Injury Association; N/A = not available.

Fig. 2A–F (A) Preinjury midsagittal CT shows the basion-dental interval within normal limits (dotted line). (B) Preinjury parasagittal CT demonstrates anatomic alignment of the occipitoatlantal joint. (C) Preinjury CT shows normal midcoronal height of the atlantoaxial

joints. (D) Postinjury midsagittal CT has evidence of increased basion-dental interval. (E) Postinjury parasagittal CT showing subluxation of the occipitoatlantal joint. (F) Postinjury midcoronal CT demonstrates increased height at the lateral atlantoaxial joints.

Table 5. Comparison of preinjury and postinjury CT measurements in Patient 4

Articular measurement (CT)	Preinjury (mm)	Postinjury (mm)
Left anterior OA height	0.8	21.8*
Right anterior OA height	0.6	19.1*
Left posterior OA height	0.5	19.9*
Right posterior OA height	0.7	15.4*
Left midcoronal atlantoaxial height	1	3*
Right midcoronal atlantoaxial height	0.5	1.8*
Basion-dental interval	5.6	22*

Measurements marked with an * are above the upper confidence interval of normal [22].

OA = occipitoatlantal.

Table 6. Comparison of prereduction and postreduction CT measurements in Patient 5

Articular measurement (CT)	Prereduction (mm)	Postreduction (mm)
Left anterior OA height	2.5*	0.9
Right anterior OA height	1.6*	0.5
Left posterior OA height	6.9*	3.2*
Right posterior OA height	6.9*	1.2
Left midcoronal atlantoaxial height	5.8*	3.3*
Right midcoronal atlantoaxial height	1.8*	2.5*
Basion-dental interval	15.5*	7.2

Measurements marked with an * are above the upper confidence interval of normal [22].

OA = occipitoatlantal.

Fig. 3A–B (A) Midsagittal CT displays substantial posterior displacement of Type II odontoid fracture. (B) Midsagittal MRI of the same patient as in A displays reduction of the odontoid fracture and intact cruciate ligaments, although there is vertical displacement of the odontoid fragments.

Fig. 4A–C (A) Midsagittal STIR MRI demonstrates destruction of the craniocervical ligament complex. (B) Midsagittal MRI displays destruction of the craniocervical ligament complex with fracture of the tip of the odontoid. (C) Midsagittal MRI image shows destruction of apical ligaments complex with subluxation of the atlantodental interval but intact cruciate complex. This scan was considered indeterminate.

consider dynamic assessment such as traction imaging to be the gold standard of diagnosis of craniocervical instability. A recent classification of occipitocervical instability includes a dynamic traction test to distinguish Type 1 “sprain” and Type 2 “rupture” injuries [30]. However, to the authors’ knowledge, the technique of a traction test to diagnose

occipitocervical instability has not been published including the weights used, positioning, and complications. Traction testing is not standard of care in acute spine trauma. Skeletal traction is considered to be relatively contraindicated in the presence of occipitocervical instability by the authors. Although articular subluxation was identified on several

patients, the joint displacement in this study was likely a result of the weight of the head or positioning. No attempt was made to distract the joints to improve diagnostic accuracy. Third, there was no specialized software to reformat the plane of measurement to the region of interest. In particular, the coronal reconstructions were oblique to the C1 lateral masses in some cases, not bisecting the C1 lateral masses as the measurement technique was described [11]. An oblique plane of measurement could erroneously increase the measurements. Fourth, we acknowledge the limitations of postinjury imaging studies that the displacement on the study may not represent the position of maximal displacement. We encourage critical evaluation of all potentially unstable injuries regardless of whether initial imaging demonstrates parameters within the normal ranges used in this article. Fifth, there is a possibility of misdiagnosis of the patients who were included in the series. Each patient was determined by consensus of the consulting orthopaedic, neurosurgical, and physiatry services to have occipitocervical instability and underwent stabilization whether through surgery or external stabilization. In contrast, other series on this topic have included patients with hangman's fractures and other injuries inconsistent with occipitocervical instability. Retrospectively, two patients who were diagnosed with craniocervical injury did not meet the updated criteria for diagnosis because both patients were noted to have intact ligamentous structures and no bony displacement. It is possible they were initially misdiagnosed or there is another subtype of craniocervical injury without radiographic abnormality, which is not evident in this series. Nevertheless, both of these patients underwent operative stabilization for presumptive craniocervical injuries so they were included in the series.

In this study, we describe craniocervical dislocation based on diastasis of the articular surfaces defined on CT, instead of the relationships of midline structures on radiographs using historical techniques [27]. Our observations suggest diastasis of the occipitoatlantal and atlantoaxial joints occurs after craniocervical dissociative injuries. We compared the pre- and postinjury CT scans of Patient 4 and determined subluxation of the occipitoatlantal and atlantoaxial joints is specific to a dislocation injury (Fig. 1; Table 4). We described the dynamic nature of the articular displacement. As the example of Patient 5 illustrates, there is tremendous mobility of the craniocervical junction, which may confound other historical classifications such as Traynelis et al. [27]. Specifically, secondary reduction maneuvers may erroneously produce normal joint heights even in the presence of significant instability, as the example of Patient 5 illustrates. Based on these examples, we surmise that classification based on the magnitude [3] or direction [27] of displacement may be confounded by the tremendous instability of these injuries.

Positioning was also described as a confounder of diagnosis of craniocervical injuries by Harris [13] using radiographs. We identified five patients with isolated atlantoaxial subluxation without occipitoatlantal subluxation. This suggests separate structures stabilize the occipitoatlantal and atlantoaxial articulations. Although isolated atlantoaxial injury was observed, occipitoatlantal injury was not seen without concomitant atlantoaxial injury. The pattern of neurological injury indicates the importance of distinguishing occipitoatlantal and atlantoaxial displacement. Patients with vertical displacement (manifested by displacement of the BDI and atlantoaxial joints) had no spinal cord injuries compared with half of the patients in the occipitoatlantal-atlantoaxial dislocation group. Based on our findings, we believe combined occipitoatlantal-atlantoaxial dislocations result in posterior translation of the spine relative to the occiput, resulting in impingement of the dens on the spinal cord. All of the complete spinal cord injuries occurred in patients with combined occipitoatlantal-atlantoaxial dislocations. The isolated atlantoaxial distractive injuries did not display AP subluxation, spinal cord contusion, or severe neurologic deficits. Proper posterior support of the cervical spine relative to the cranium may be important for these injuries. The goal of operative reconstruction should include anatomic realignment, including attention to translation of the joints to decompress the spinal cord and optimize potential for rehabilitation [10, 17, 20, 21].

Disruption of the occipitoatlantal joint capsule on MRI was associated with occipitoatlantal joint space distraction in this study. Previous classifications and diagnostic criteria have relied on the integrity of the cruciate ligament to diagnose craniocervical injuries [2, 8–10, 29]. Horn et al. [14] report a dichotomous classification including occipitoatlantal and isolated atlantoaxial dislocations based on cruciate ligament integrity [19]. Although the craniocervical ligament is considered the main stabilizer of the craniocervical junction, its integrity did not correspond to the pattern of joint displacement or neurologic injury in this series. Five patients were identified with cruciate ligament injury without any joint subluxation. Additionally, there was no specific pattern of cruciate ligament disruption to distinguish occipitoatlantal-atlantoaxial and isolated atlantoaxial injuries. We propose the occipitoatlantal joint capsular ligaments may serve as a secondary stabilizer of the occipitoatlantal joints because their integrity corresponded with joint instability in our series. Articular capsules have been identified as important secondary stabilizers in other joints in the spine [25]. Other clinical studies have questioned the role of the craniocervical ligament complex and odontoid in maintenance of craniocervical stability. First, there is some anatomic variability in the structure of the craniocervical ligament

complex and some patients are missing the apical ligament [28]. In a case series of 27 heterogeneous patients who underwent transoral resection of the odontoid, anterior arch of C1, and lower clivus (and presumably destruction of the cruciate ligament complex), eight of 27 did not develop craniocervical instability postoperatively [6, 23]. Additionally, circumferential fracture of the skull base resulting in bilateral occipital condyle fractures with intact craniocervical ligaments has also been reported as a cause of craniocervical dislocation [23]. Further study of the occipitoatlantal joint capsules as stabilizers of the craniocervical junction is warranted; the cruciate ligament may not be the main stabilizer of the craniocervical junction.

Two discrete patterns of injury emerged from these data (Fig. 5). Isolated atlantoaxial dislocations (Fig. 5B) were

distinguished from occipitoatlantal dislocations (Fig. 5C) by integrity of anatomic structures (occipitoatlantal capsular ligament) and the lower prevalence of complete spinal cord injuries in the former. We include the patients with isolated cruciate ligament injuries and no joint subluxation into the category of isolated atlantoaxial joint injuries because these patients may have manifested atlantoaxial instability with displacement. Additionally, there was no occipitoatlantal capsular injury in these patients. We propose a new diagnostic algorithm based on these criteria (Table 7). In this scheme, displacement, ligamentous integrity of the occipitoatlantal and cruciate ligaments, and neurological injury would be evaluated as separate categories and the highest category dictates the type of injury. No previous classification of occipitocervical instability

Fig. 5A–C (A) Diagram depicting the anatomical relationships and occipitoatlantal joint capsule in normal individuals. The capsule extends from the anterosuperior aspect of the C1 lateral mass to insert on the skull anterior to the occipital condyle. (B) Diagram depicting an isolated atlantoaxial craniocervical dislocation. Note the integrity of the occipitoatlantal ligament and disrupted cruciate ligament. (C) Diagram depicting a combined occipitoatlantal-atlantoaxial craniocervical dislocation. Note the disrupted occipitoatlantal and cruciate ligaments.

Table 7. Proposed classification of occipitocervical dissociative injuries

Type	Type	OA capsule	Craniocervical ligaments	Displacement	Treatment
I	Atlantoaxial	Intact	Disrupted	Basion-dental interval, C1-C2 Joints	C1-C2 fusion
II	Occipitoatlantalaxial	Disrupted	Disrupted	Basion-dental interval, OA joints, C1-C2 joints	Occiput to C2

OA = occipitoatlantal.

integrates displacement, ligamentous injury, and neurologic injury into the algorithm [8–10, 17]. Under this algorithm, clinicians could consider patients with Type I injuries as possible candidates for isolated C1–C2 fusion, whereas Type II injuries would be an absolute indication for occiput–C2 fusion. Patients with Type II injuries should also undergo immediate closed reduction and provisional stabilization to prevent AP translation and dens impingement on the spinal cord while undergoing emergency workup.

Our data suggest craniocervical injuries are associated with possible disruption of the occipitotlantal joint capsule on MRI and subluxation of the occipitotlantal or atlantojoints. We believe relying on displacement alone to indicate occipitocervical dissociation may result in failure to recognize some injuries. MRI identification of disruption of the occipitotlantal joint capsules or stabilizing ligaments corresponded with instability and may potentially identify patients who were at risk for secondary AP instability and catastrophic neurologic injury. Based on these findings, we propose patients with craniocervical region injury fall into one of two categories based on anatomic and imaging characteristics. Further studies on this topic, including detailed biomechanical studies, are indicated to explicitly define the role of the occipitotlantal joint capsules in providing structural stability and the relationship between occipitotlantal displacement seen on imaging and biomechanical instability.

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