Original Article

Radiologic utility of the Gehweiler and AO spine classification systems for C1 Trauma: A retrospective review from a Level I trauma center

ABSTRACT

Objective: The purpose of our study was to identify adult trauma patients with an acute C1 burst fracture, evaluate for concomitant transverse atlantal ligament (TAL) injury, and apply the modified Gehweiler and AO spine classification systems to determine the utility of these classification systems in accurately defining C1 trauma.

Materials and Methods: Adult trauma patients with an acute C1 fracture were identified retrospectively using Nuance mPower software. The C1 fracture was described based on whether the fracture involved the anterior arch, posterior arch, lateral mass, medial tubercle, and/or transverse process. If follow-up cervical magnetic resonance imaging (MRI) was performed, the presence and location of an associated TAL injury was recorded. The anatomic location of the C1 burst fracture and TAL injury, if present, were compared with the descriptive classification systems outlined by Gehweiler/Dickman (modified) and the AO Spine society. Any additional osseous trauma of the skull base and C1-C2 was also recorded along with relevant clinical history and management.

Results: Thirty-nine patients were identified with an acute C1 burst fracture on cervical computed tomography (CT) with seventy-seven percent of patients undergoing follow-up cervical MRI. Observed fracture patterns were divided into five distinct types based on CT findings and further subdivided based on the integrity of the transverse altantal ligament on MRI. TAL tears were observed exclusively in type 3 fractures (anterior and posterior arch fractures) and type 4 fractures (anterior arch, posterior arch, and lateral mass fractures). The modified Gehweiler classification system failed to accurately describe the anatomic location of the C1 fracture in forty-four percent of patients, whereas the AO spine was too broad and failed to accurately describe fracture location in our cohort.

Conclusions: The Gehweiler and AO spine classifications demonstrated significant shortcomings in the accurate description of patients with C1 trauma. Whereas the Gehweiler system did not accurately describe the anatomic location of the various C1 fractures, the AO spine system was too broad and failed to radiologically classify fracture location. Moreover, there was a high number of patients with AO spine type B injuries without atlantoaxial translation that nevertheless required C1-C2 fusion for atlantoaxial instability. We suggest the need for an updated classification system that takes into account both the CT (fracture location) and MRI (TAL integrity) appearance of C1 trauma. An updated classification strategy will offer a radiologic standardization of C1 trauma that will aid in future research studies and help optimize patient management.

Keywords: Craniocervical junction, magnetic resonance imaging, trauma

Peter Fiester, Dinesh Rao, Erik Soule, Matthew Jenson, Jeet Patel, Emilio Supsupin, Gazanfar Rahmathulla[1], Daryoush Tavanaiepour[1]

Department of Radiology, University of Florida Health, [1]Department of Neurosurgery, University of Florida College of Medicine, Jacksonville, Florida, USA

Address for correspondence: Dr. Peter Fiester, Department of Radiology, University of Florida Health, 655 West 8th Street, Jacksonville, Florida 32209, USA.
E-mail: peter.fiester@jax.ufl.edu

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INTRODUCTION

Multicentric fractures of the atlas are commonly referred by their eponym as "Jefferson" fractures (named for the British surgeon who first described them) and may affect any part

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of the C1 vertebrae [Figure 1]. The original and most widely used classification system for atlas fractures was developed by Gehweiler *et al.*, which divided C1 fractures into five types based on fracture location.[1] Type 1 and 2 fractures are isolated fractures of the anterior and posterior arch, respectively. Type 3 fractures involve both the anterior and posterior arch and were further subdivided into fractures with an intact transverse atlantal ligament (TAL) and torn TAL – types 3a and 3b, respectively. Finally, Type 4 and 5 fractures are isolated fractures of the C1 lateral mass and transverse process, respectively [Figure 2]. Dickman *et al.* later subdivided a subset of C1 fractures depending on the presence and type of associated TAL injury.[2] An avulsion of the medial tubercle (Dickman type 1) was considered a stable injury that may be treated conservatively with external immobilization, whereas a mid-substance TAL injury (Dickman type 2) requires C1-C2 fusion since external immobilization or C1 osteosynthesis will likely not correct the TAL deficiency and the subsequent atlantoaxial instability. More recently, studies have begun to question this treatment paradigm, and the overall contribution of the TAL in maintaining atlantoaxial stability has become more controversial.[3-5]

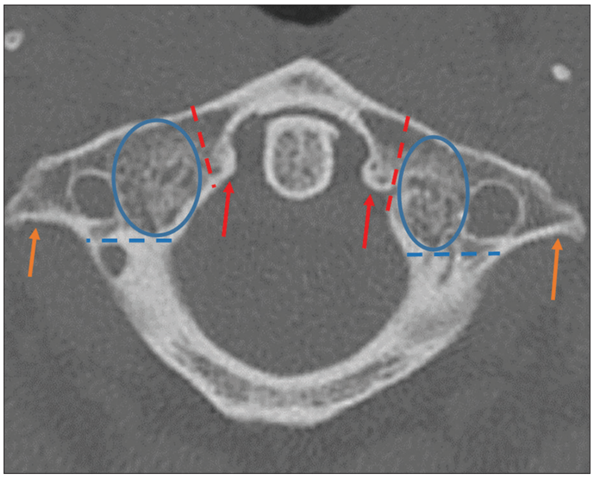

Figure 1: Axial CT demonstrating the anatomic components of the C1 vertebrae – including the anterior arch (bounded by red dashed lines), posterior arch (bounded by blue dashed lines), lateral masses (blue ovals), medial tubercles (red arrows), and transverse processes (orange arrow). CT - Computed tomography

Subsequently, the AO spine society was tasked with the development of a new classification system for upper cervical spine trauma that organized C1 fractures into three groups: (1) isolated bony fractures of the C1 vertebra (type A stable); (2) C1 fractures plus TAL injuries without atlantoaxial translation (type B stable or unstable); and, (3) C1 fractures plus TAL injuries with atlantoaxial translation in any plane (type C unstable)[6] [Figure 3]. Patient neurologic symptoms (N) and descriptive modifiers (M) were added to this classification system.

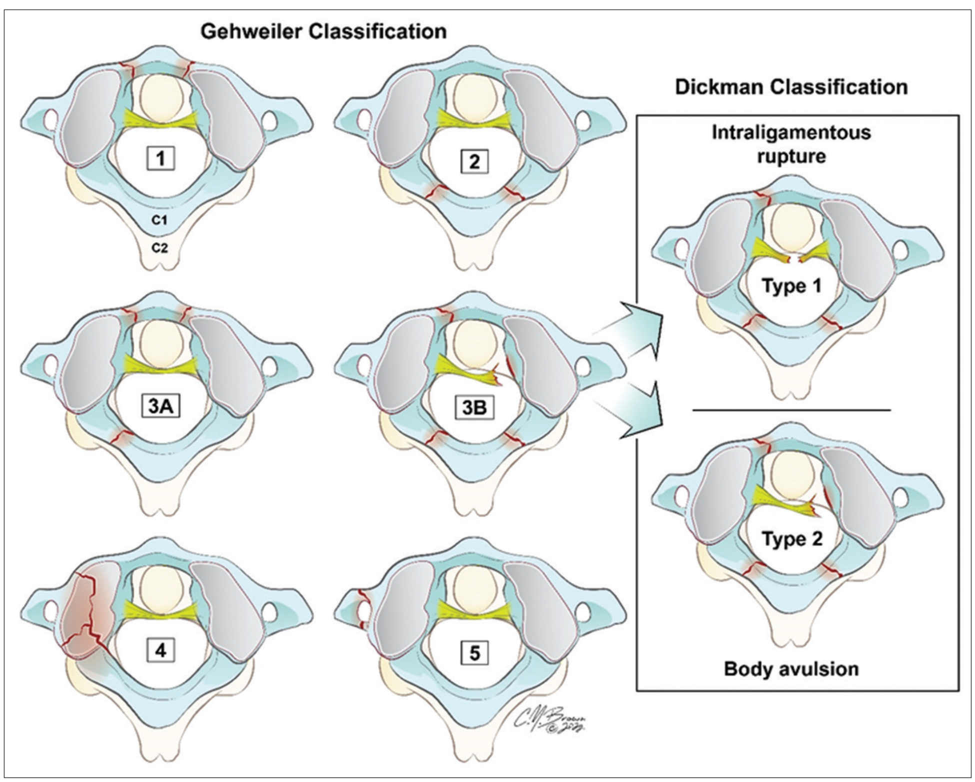

Figure 2: Illustration demonstrating the Gehweiler classification of C1 fractures based on fracture location with the Dickman subclassification based on the type of transverse atlantal ligament injury

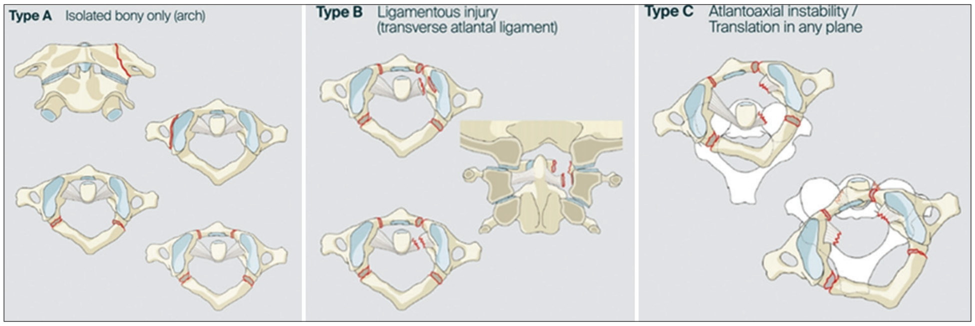

Figure 3: AO Spine classification system for C1 trauma, including Type A injury (isolated C1 ring fracture), Type B injury (C1 ring fracture plus transverse atlantal ligament tear), and Type C injury (C1 ring fracture, transverse atlantal ligament tear, and atlantoaxial translation)

The purpose of our study was to retrospectively apply the modified Gehweiler (combined Gehweiler and Dickman classification systems) and AO spine classification systems to patients with an acute fracture of the C1 vertebrae to determine the accuracy of these methods in describing the radiologic appearance of an acute C1 fracture. In patients with a follow-up cervical MRI, we also evaluated the integrity of the TAL. We hypothesize that these classification systems may not accurately define the radiologic appearance of all C1 injuries in our patient cohort.

MATERIALS AND METHODS

A waiver of informed consent was granted by the institutional review board to retrospectively evaluate the imaging and clinical findings of adult trauma patients with a C1 fracture. Thirty-nine patients who presented to the emergency department with a confirmed acute C1 fracture on cervical CT were identified retrospectively by using the keywords “C1 fracture” and “Jefferson fracture” included in CT reports between January 2015 and January 2021 using Nuance mPower software (Nuance Communications, Inc., Burlington, Massachusetts, USA). C1 fracture location and number was recorded and subdivided based on conventional anatomy as involving the anterior arch, posterior arch, medial tubercle, lateral mass, and/or transverse process. If the patient underwent a follow-up cervical MRI within 48 h, lateral mass, medial tubercle, posterior arch, the TAL was evaluated for injury and injury location.

Patient selection

Inclusion criteria included all adult trauma patients who presented to our Level I trauma center with a confirmed acute C1 fracture on cervical CT. Exclusion criteria included pediatric patients <16 y/o, nontrauma patients, and patients with imaging findings of a chronic C1 fracture (bony callous formation, fracture with corticated margins, and/or prior imaging demonstrating chronicity). Patients with excessive inflammatory pannus or osteoarthritis of the atlantoaxial joint on cervical MRI that obscured the TAL were also excluded from the study. Patients who did not receive a cervical spine MRI within 48 h of presentation were also excluded from the study. Confirmation of an acute C1 fracture was agreed upon in consensus by two CAQ certified neuroradiologists with experience and prior research in craniocervical trauma.

Imaging protocols

CT and MRI exams were performed using the standard departmental protocols. CT images were generated with 0.625 mm slice thickness and reconstructed using multiplanar bone and soft tissue algorithms (GE medical systems). Evaluation for C1 bony trauma utilized multiplanar, orthogonal reconstructions using a thin section bone kernel window. MRI studies were performed on a 1.5 Tesla magnet with a head and neck coil (Avanto, Siemens). Slice thickness was 3 mm and sagittal T1, T2, and STIR as well as axial T2, and T2 Multi-Echo Data Image Combination sequences were obtained. All MRI sequences were comprehensively reviewed and TAL injury location and type were agreed upon in consensus.

Magnetic resonance imaging criteria for injury

All cervical MRI exams were graded as nondiagnostic, limited, or diagnostic quality. TAL injuries were confirmed primarily on T2 and STIR axial and sagittal MRI sequences when there was clear disruption of the normal dark T2 hypointense ligament and increased T2 signal within the ligament. The TAL was also considered injured if the ligament was not visible and replaced with hematoma (ruptured ligament). The location of the TAL injury was recorded as right, left, midline, or bilateral in relation to the C2 dens.

RESULTS

A total of 39 adult patients (14 females and 25 males) were identified with an acute C1 burst fracture on cervical CT [Table 1]. The median age was 57 years old with a range between 16 and 95 years old. The mechanism of trauma involved motor vehicles exclusively, either primary motor

Table 1: 39 patients with acute C1 arch fracture ("Jefferson fracture") including mechanism of injury, fracture location, transverse atlantal ligament integrity on magnetic resonance imaging (if available), and any concomitant C1–C2 fractures

Age/sex	Mechanism of injury	C1 burst fracture type	TAL tear	Additional cervical fracture
29/male	MVA	Anterior arch	None	None
57/male	MVA	Posterior arch	None	None
68/male	Pedestrian versus motor vehicle	Ant/postarch	Yes	None
94/male	MVA	Ant/postarch	Yes	None
73/male	MVA	Ant/postarch	None	Type 2 dens
54/male	MVA	Ant/postarch	Yes	None
75/male	MVA	Ant/postarch	None	Type 2 dens
80/male	MVA	Ant/postarch	None	None
72/male	MVA	Ant/postarch	None	Bilateral C2 pars
85/male	MVA	Ant/postarch	None	None
64/male	Pedestrian versus motor vehicle	Ant/postarch	None	Type 2 dens
57/female	MVA	Ant/postarch	None	None
85/male	MVA	Ant/postarch	None	None
47/female	MVA	Ant/postarch	None	Type 2 dens
77/female	MVA	Ant/postarch	None	Type 2 dens
74/male	MVA	Ant/postarch	Yes	Type 2 dens
61/female	MVA	Ant/postarch; lateral mass	None	None
24/male	MVA	Ant/postarch; lateral mass	None	None
42/male	Pedestrian versus motor vehicle	Ant/postarch; lateral mass	None	None
69/male	MVA	Ant/postarch; lateral mass	None	None
30/female	MVA	Ant/postarch; lateral mass	Yes	None
28/male	MVA	Ant/postarch; lateral mass	Yes	None
33/female	MVA	Ant/postarch; lateral mass	Yes	None
37/male	MVA	Ant/postarch; lateral mass	Yes	None
27/male	MVA	Ant/postarch; lateral mass	Yes	None
16/female	MVA	Ant/postarch; lateral mass	None	Type 3 dens
47/male	MVA	Ant/postarch; lateral mass	None	None
53/male	MVA	Ant/postarch; lateral mass	None	None
44/male	MVA	Ant/postarch; lateral mass	None	None
57/male	MVA	Ant/postarch; lateral mass; transverse process	None	None
77/female	MVA	Posterior arch	N/A	Type 3 dens
47/female	MVA	Ant/postarch	N/A	Type 2 dens
52/female	MVA	Ant arch, lateral mass	N/A	None
26/male	MVA	Ant/postarch	N/A	Type 2 dens
50/female	MVA	Ant/postarch; lateral mass	N/A	None
79/male	MVA	Ant/postarch	N/A	Type 2 dens
87/female	MVA	Ant/postarch	N/A	Type 2 dens
21/female	MVA	Ant/postarch	N/A	None
63/ female	MVA	Ant/postarch	N/A	Type 3 dens

TAL - Transverse atlantal ligament, N/A - Not available, MVA - Motor vehicle accident

vehicle accidents or pedestrians or bicyclists struck by motor vehicles (six patients). Nine patients did not receive a cervical MRI within 48 h and were excluded from data analysis with respect to ligamentous integrity.

Five distinct patterns of C1 fracture were observed in our cohort based on C1 anatomy and fracture location on cervical CT and divided into types 1 through 5. Type 1 fractures were isolated fractures of the anterior arch (1 patient). Type 2 fractures were isolated fractures of the posterior arch (one patient) [Figure 4]. Type 3 fractures involved both the anterior and posterior arch (20 patients) [Figure 5]. Type 4 fractures involved the anterior arch, posterior arch, and C1 lateral mass (16 patients) [Figure 6]. Type 5 fractures involved the transverse process with an anterior arch, posterior arch, or lateral mass fracture (one patient). In those patients who underwent cervical MRI, TAL tears were observed exclusively in type 3 fractures (anterior and posterior arch fractures) and type 4 fractures (anterior arch, posterior arch, and lateral mass fractures).

The utility of the modified Gehweiler classification for atlas fractures was applied to our patients. Forty-four percent of

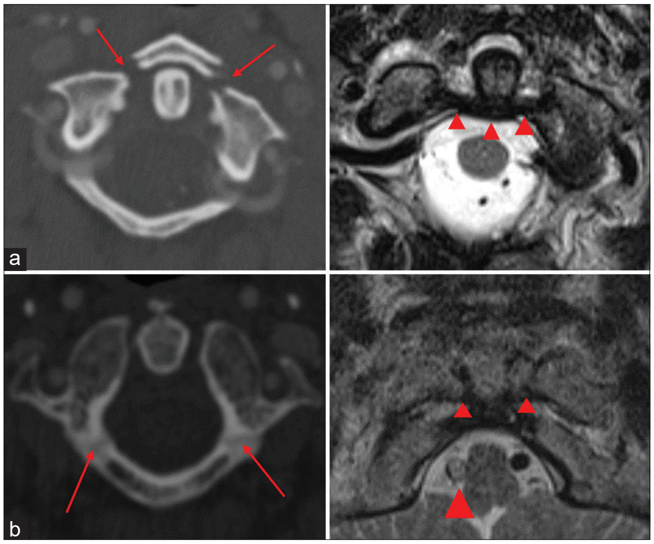

Figure 4: (a) Axial CTA of the cervical spine (left) in a 29 year old trauma patient status post MVA demonstrating diastatic, bilateral C1 anterior arch fractures (red arrows). Axial T2 weighted MRI (right) in the same patient demonstrating an intact transverse atlantal ligament. The patient was treated with prolonged external immobilization without persistent neurologic deficits. (b) Axial CT of the cervical spine (left) in a 77 year old trauma patient status post MVA demonstrating subtle, nondisplaced bilateral C1 posterior arch fractures (red arrows). Axial T2 weighted MRI (right) in the same patient demonstrates an intact transverse atlantal ligament (red arrows) and right intradural vertebral artery traumatic dissection (red arrowhead). CT - Computed tomography, MRI - Magnetic resonance imaging, MVA - Motor vehicle accident, CTA - Computed tomography angiography

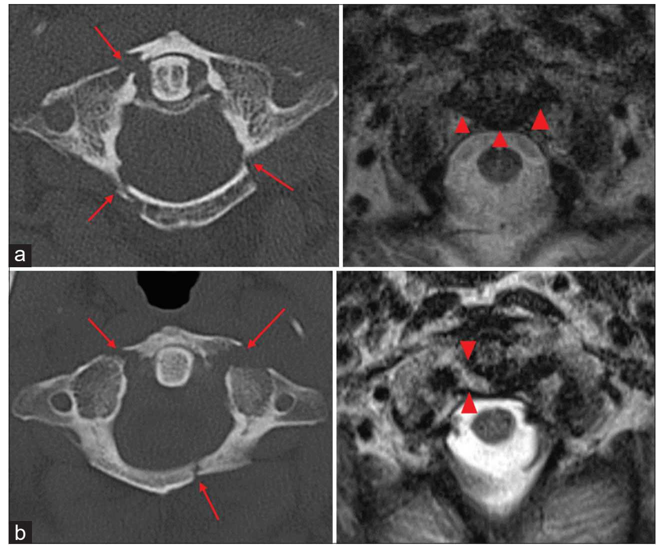

Figure 5: (a) Axial CT of the cervical spine (left) in a 72 year old trauma patient status post MVA demonstrating a right C1 anterior arch fracture and bilateral C1 posterior arch fractures (red arrows). Note is made of a mineralized transverse atlantal ligament (red arrowheads). Axial T2 weighted MRI (right) in the same patient demonstrates an intact transverse atlantal ligament (red arrows). (b) Axial CT of the cervical spine (left) in a 54 year old trauma patient status post MVA demonstrating bilateral C1 anterior arch fracture and left C1 posterior arch fractures (red arrows). Axial T2 weighted MRI (right) in the same patient demonstrating a torn right transverse atlantal ligament (red arrowheads). CT - Computed tomography, MRI - Magnetic resonance imaging, MVA - Motor vehicle accident

our patient cohort with a C1 fracture could not be accurately categorized according to this classification system. There was no accurate Gehweiler classification description for C1 fractures with anterior and posterior arch fractures with TAL injuries (four patients) and patients with both anterior/posterior arch and lateral mass fractures (13 patients). There were no observed isolated lateral mass fractures (Gehweiler type 4) or transverse process fractures (Gehweiler type 5) in our patient cohort. In addition, the utility of the AO Spine Society Classification system was applied to our patients who underwent both CT and MRI. This classification system broadly described 100% of our patient cohort (21 patients suffered type A injury, eight patients suffered type B injury, and 1 patient suffered type C injury), but, by the nature of the AO Spine criteria, the anatomic location of the C1 fracture could not be classified. Thirty-eight percent of patients with a type B injury and the one patient with type C injury underwent C1–2 fusion for atlantoaxial instability.

The presence of additional bony trauma of the craniocervical junction (CCJ) was evaluated with a significant percentage of patients demonstrating a concomitant C2 fracture (type 2 dens fracture - six patients; type 3 dens fracture - 1 patient; and pars interarticularis fracture - 1 patient). The atlanto-occipital joint measured <2 mm in all patients with no observed CT findings of atlanto-occipital dislocation.

DISCUSSION

Strictly applying the Gehweiler/Dickman classification of atlas fractures to our thirty-nine patients with acute C1 trauma failed to properly categorize nearly half of our patient cohort. The most common fractures that escaped classification were for C1 fractures with anterior and posterior arch involvement with TAL injuries (three patients) and patients with combined anterior/posterior arch fractures with lateral mass fractures (13 patients). In addition, we did not observe any C1 fractures with isolated involvement of the lateral mass or transverse process – the Gehweiler types 4 and 5 fractures, respectively. The AO spine classification system broadly categorized all C1 trauma in our patient cohort using the Type A-C classification system, but it did not inherently define the anatomic location of the C1 fracture or TAL injury. Furthermore, Type B/C designation was a poor predictor in determining which patients underwent operative fixation for atlantoaxial instability.

Several reasons may account for this discrepancy in C1 fracture classification with the most evident being the significant improvement in radiologic imaging between the publication of the "The Radiology of Vertebral Trauma" in 1980 by Gehweiler, which primarily relied on observations of C1 fracture location by plain film, and the widespread

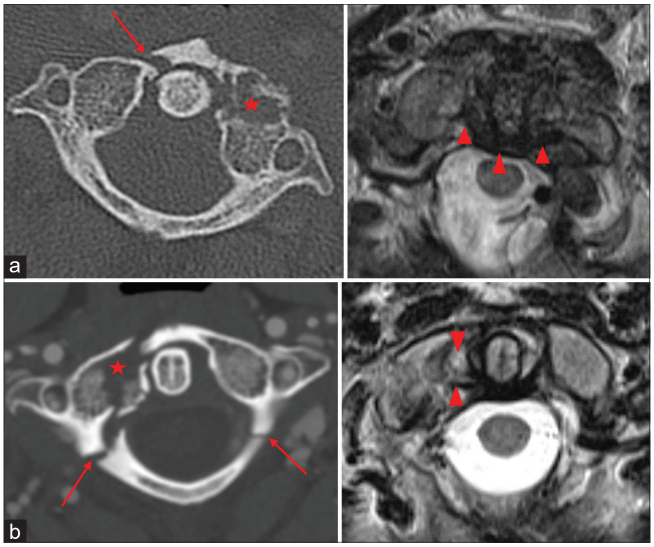

Figure 6: (a) Axial CT of the cervical spine (left) in a 30 year old trauma patient status post MVA demonstrating a right C1 anterior arch fracture (red arrow) and comminuted left C1 lateral mass fracture (red star). Axial T2 weighted MRI (right) in the same patient demonstrates an intact transverse atlantal ligament (red arrowheads). (b). Axial CT of the cervical spine (left) in a 30 year old trauma patient status post MVA demonstrating bilateral C1 posterior arch fractures (red arrows) and comminuted, right C1 lateral mass fracture (red arrowhead). Axial T2 weighted MRI (right) in the same patient demonstrates a torn right transverse atlantal ligament (red arrows). CT - Computed tomography, MRI - Magnetic resonance imaging, MVA - Motor vehicle accident

availability and utilization of cervical CT and MRI today.[1,7,8] As the novel classification scheme for atlas fractures, the Gehweiler classification has been perpetuated in the literature, but never rigorously tested in a radiologic sense as an adequate descriptor of C1 bony trauma. In addition, incorporating cervical MRI findings, which allows direct inspection of the TAL for injury, allows a more accurate description of C1 injuries and for classifying C1 trauma in the context of persistent atlantoaxial instability.[9-13]

An important modification of the Gehweiler classification was later added by Dickman *et al.* in 1996 to help guide neurosurgical management.[2] Their analysis was based on 39 patients with either a TAL injury directly evaluated by MRI or a presumed TAL injury based on the presence of a C1 lateral mass or medial tubercle fracture on CT. This description classified a subset of C1 fractures based on the presence and location of an associated TAL injury and asserted that C1 vertebral fractures with mid-substance TAL tear (Dickman type 1) requires C1-C2 fusion since external bracing and C1 osteosynthesis will not stabilize the incompetent TAL. In contrast, a bony avulsion of the medial tubercle or a lateral mass fracture, with an otherwise intact TAL (Dickman type 2), may be treated conservatively. Essentially, the distinction relies on the principle that an avulsion fracture will eventually fuse preventing persistent atlantoaxial instability, whereas a torn ligament will not heal resulting in persistent instability. More recently, this conclusion by Dickman has been challenged with several studies demonstrating the success of restoring C1 ring integrity utilizing C1 osteosynthesis in preventing atlantoaxial instability in TAL-deficient C1 ring fractures.[3,4] The AO spine classification system broadly described C1 injuries in our patient cohort, but this classification system failed to radiologically define the anatomic location of the C1 fracture and the location of the TAL injury as mid-substance injury versus a bony avulsion of the medial tubercle.

The purpose of an updated atlas fracture classification system is manifold. Radiologically, the eponym "Jefferson" fracture has become ubiquitous in describing any and all types of multicentric C1 vertebral fractures with little distinction for fracture type, location, and displacement. A standardized description that incorporates CT findings (to accurately describe fracture location with MRI findings (to determine TAL integrity and injury location) will facilitate standardized communication between radiologists and neurosurgeons. Ideally, this standardized reporting scheme would help stratify patients into operative versus nonoperative management based on the status of the TAL as determined by cervical MRI. Given the potentially life-threatening nature of the C1 trauma and conflicting treatment paradigms in the literature, a thorough anatomic and functional description of C1 injuries is long overdue.[14,15] Second, by parsing these injuries based on fracture location and TAL integrity, future research studies can examine the management and outcome of different types of C1 injuries to optimize patient care. Considering the significant reduction in range of motion, decreased functional outcomes, and lower quality of life of patients who undergo C1-C2 fusion compared with C1 osteosysnthesis or temporary external fixation, further research and optimization of care for C1 injuries is especially warranted.[16,17]

Finally, concomitant trauma of the CCJ was analyzed with one third of patients demonstrating a C2 fracture, most commonly a type II/III dens fracture, with the vast majority of C2 fractures occurring in the setting of an intact TAL. Mechanistically, the association between a C1 fracture (axial load injury) and C2 dens fracture (hyperflexion injury) implies an overlap between two disparate forces at the time of the trauma such that occurs with the potential multivector trauma from motor vehicle accidents that may include both a decelerating and axial load force. Interestingly, there were no associated cases of atlanto-occipital widening on cervical CT, no overt cases of atlanto-occipital dislocation, and no patients requiring occipital cervical fusion for CCJ instability in our patient cohort.

Our study had several limitations. Although to our knowledge we collected the largest cohort of C1 fractures in the radiology literature, the relatively small sample size may potentially impede the utility of our classification system. Multiregional research studies with a larger sample size would improve the accuracy of this classification system and assist in targeted research studies comparing operative versus nonoperative management in the different C1 injury types. In addition, there was a small but significant number of patients who did not obtain a follow-up MRI. Although all of these patients were managed with temporary external bracing without persistent atlantoaxial instability, the TAL could not be directly evaluated which limited the impact of the study. Finally, since our analysis was retrospective, the possibility of interpreter error and reinforcement bias is possible.

CONCLUSIONS

The modified Gehweiler and AO spine classification systems demonstrated limited applicability in the accurate description of C1 trauma in our patient cohort. Nearly half of patients were not defined by the Gehweiler classification, and the AO spine classification failed to define the anatomic location of the C1 fractures. Precise classification of C1 trauma is paramount since there is conflicting data regarding neurosurgical management of C1 trauma and the potential for future atlantoaxial instability. An updated classification system that incorporates both CT findings for fracture location/displacement and MRI findings to assess TAL integrity is the next logical step in the standardization and management of patients with C1 trauma.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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