Diagnosis and management of isolated C1 fractures: A systematic review

ABSTRACT

Objective: Atlas fractures are a common craniocervical injury, often resulting from trauma. However, diagnosis and management of atlas fractures continues to be the subject of controversy. We aimed to characterize the factors related to diagnosis of atlas fractures, delineate important considerations in selecting the optimal management for a patient with an atlas fracture, and compare outcomes of surgical and conservative management.

Methods: We performed a systematic review using PubMed, Embase, and Scopus to identify articles that analyzed diagnosis and management of isolated atlas fractures published between 2013 and 2020. Titles and abstracts were screened. Studies meeting prespecified inclusion criteria were reviewed in full.

Results: Of 305 resultant articles, 13 were included. C1:C2 ratio and lateral mass displacement (LMD) were used to predict transverse atlantal ligament (TAL) injury. Surgery promoted high fusion rates overall. Stable atlas fractures achieved high fusion rates with conservative management, while spinal fusion promoted greater fusion rates than halo vest immobilization management for unstable fractures. Visual Analog Scale scores, range of motion, and/or LMD improved after surgery. LMD increased for unilateral sagittal split fractures with TAL injury after conservative treatment.

Conclusion: Stable atlas fractures can be sufficiently treated conservatively. Unstable atlas fractures can be managed both conservatively and surgically, while surgery is associated with favorable outcomes for unstable isolated atlas fractures. Future studies are necessary to further guide risk stratification and treatment approaches in management of the patients with isolated atlas fractures.

Keywords: Atlas fracture, atlas fractures, C1 fracture, C1 fractures

INTRODUCTION

Atlas fractures comprise 25% of craniocervical injuries, 10.6% of all cervical fractures, and 1%–3% of all spinal injuries.[1,2] The incidence of atlas fractures is rising, particularly in the elderly population.[1] Although motor vehicle accidents are responsible for 80%–85% of all atlas fractures, with injury resulting from axial loading, the type of atlas fracture depends on the speed of axial force impact.[2-4] Approximately 19%–44% of all atlas fractures are associated with an additional axis fracture, while 7% are associated with an additional subaxial cervical fracture.[1,2]

Management of atlas fractures varies depending on factors such as cervical stability, physician preference, and type of fracture. The transverse atlantal ligament (TAL) is often torn in atlas fractures, rendering the upper cervical spine unstable.[2,5,6] The Rule of Spence stipulates that lateral mass displacement (LMD) >6.9 mm is associated with TAL tear.[5]

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Dickman *et al*. instead recommended the use of magnetic resonance imaging (MRI) to more accurately ascertain TAL injury, classifying atlas fractures depending on ligamentous or avulsion injury of TAL.[6] While stable atlas fractures have traditionally been managed with cervical collar or halo vest, unstable atlas fractures have been treated surgically or with halo vest.[2,7] However, diagnosis and management of atlas fractures continues to be the subject of controversy.

Given the lack of clear guidelines regarding diagnosis and management of isolated atlas fractures, we conducted a systematic review of recent literature to examine the scope of management of isolated atlas fractures. We aimed to: (1) characterize the factors related to diagnosis of atlas fractures, (2) delineate important considerations in selecting the optimal management for a patient with an atlas fracture, and (3) compare outcomes of surgical and conservative management. Our findings may guide neurosurgeons and orthopedic surgeons in diagnosing and managing patients with atlas fractures.

METHODS

A systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to investigate the diagnosis and management of atlas fractures.[8] PubMed and MEDLINE (National Library of Medicine), Embase (Elsevier), and Scopus (Elsevier) were searched in for articles using the keywords: "atlas fracture," "atlas fractures," "C1 fracture," "C1 fractures," "Jefferson fracture," and "Jefferson fractures." The following restrictions were applied for the search: published in or translated into the English language, published between 2013 and 2020, and with abstract and full text available. The search included only articles after 2013 because the focus of this systematic review was to identify developments in the diagnosis and management of atlas fractures since the last systematic review was published in that year.[9] The protocol for this systematic review was not registered, and no funding was received.

After completing the search, duplicates were removed. The remaining articles were screened for relevance by title and abstract. Articles included for full-text review were screened for final inclusion based on the following prespecified inclusion criteria: diagnosis of isolated atlas fracture and describing diagnostic considerations or outcomes of conservative or surgical management. A second reviewer replicated the screening, and disagreements were reconciled.

After articles were selected for inclusion, a review was conducted of study characteristics including bibliographic data, aim, design, participants, diagnosis, management, and outcomes. Outcomes were prespecified. The primary outcomes of interest were fusion rate and clinical improvement. Secondary outcomes were Visual Analog Scale (VAS) score, range of motion (ROM), radiographic measurements, blood loss, operative time, neurologic improvement, disability, and complications. Critical appraisal of included studies was performed by adapting levels of evidence for prognostic studies previously described.[10] The Cochrane ROBINS-I tool was used to assess the risk of bias for included studies.[11] A judgment on the overall risk of bias for this systematic review was determined based on the risk of bias for the included studies.

RESULTS

A total of 305 articles were returned in the database searches, of which 13 articles were included in this systematic review.[12-24] Figure 1 demonstrates the PRISMA flow diagram for this study. Study design included 10 (73.3%) case series and 2 (20.0%) retrospective cohort studies and 1 (6.7%) prospective cohort study. There were 10 (80.0%) single-country studies and 3 (20.0%) collaborations. Of the single-country studies, the greatest number of studies originated from China with 3 articles and Korea and the United States with 2 articles each. All three collaborations were between China and the United States. Given the case series-provided level IV evidence, this study provides level IV evidence. There was a high risk of bias overall.

Diagnosis

Three articles reviewed various diagnostic factors relevant to the management of isolated atlas fractures [Table 1].[19,20,23] All three studies examined TAL injury in patients with atlas fractures. Lin *et al*. determined that a C1:C2 ratio >1.10 on radiographs had a sensitivity of 80% in predicting TAL injury, while a C1:C2 ratio >1.12 had a 100% specificity. All patients with ratio ≥1.15 had rupture confirmed by MRI or computed tomography (CT).[19] Park *et al*. determined that total LMD >5.9 mm and unilateral LMD >4.3 mm were associated with TAL injury in patients with unilateral sagittal split fracture of the lateral mass of C1.[23] Liu *et al*. reported that LMD <6.9 mm was inaccurate in either excluding TAL injury or predicting clinical outcomes in nonoperatively treated atlas fractures, while LMD >6.9 mm accurately determined TAL injury but not atlantoaxial stability.[20] Dickman's classification of TAL injury was more accurate in predicting atlantoaxial stability for nonoperatively treated atlas fractures.[20]

Fusion rates

Ten articles reviewed treatment of patients presenting with isolated atlas fractures [Table 2].[12-18,21,22,24] Three studies

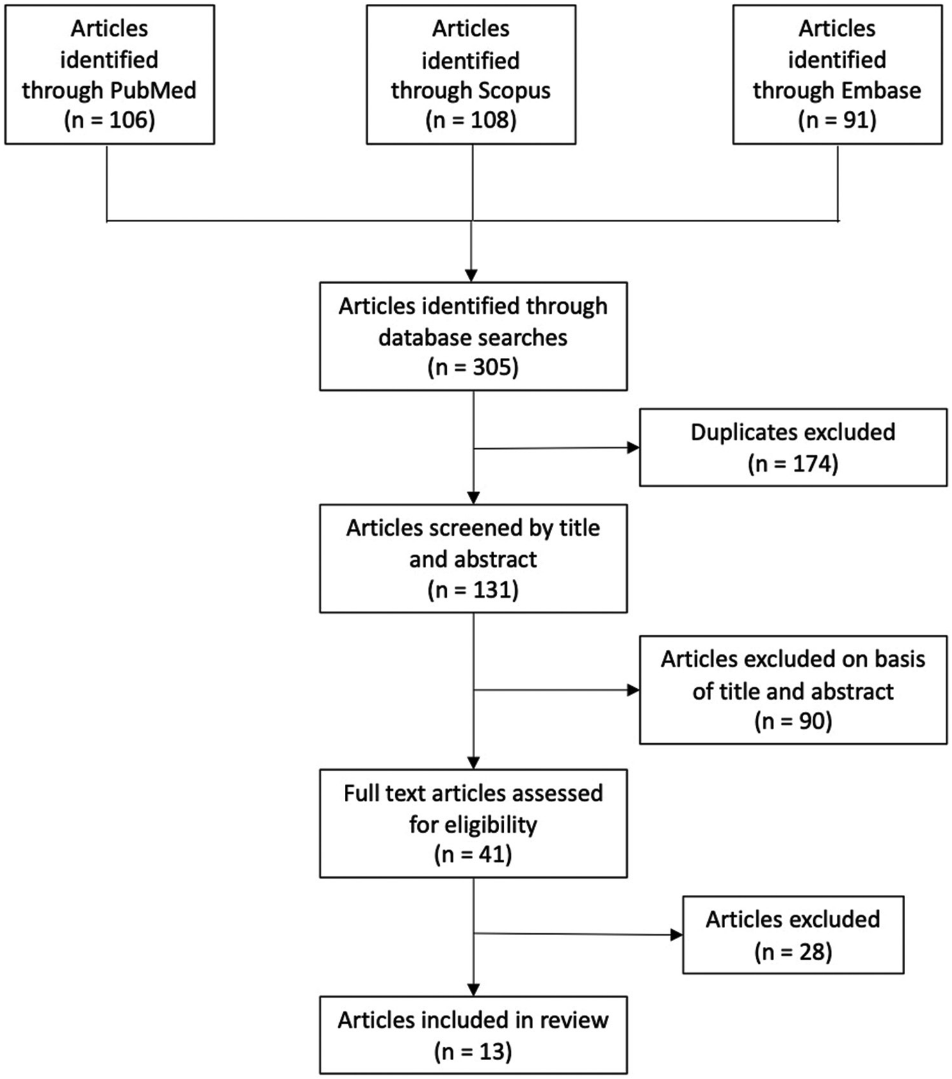

Figure 1: (Original source) PRISMA flowchart. PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

utilized the Rule of Spence in the classification of TAL injury and subsequent management.[16,18,21] All six studies examining outcomes of unstable atlas fractures found favorable fusion rates with any form of surgery,[12-14,18,22,24] while one study examining stable atlas fractures found favorable fusion rates with conservative management.[15]

All five studies examining surgical management of atlas fractures alone found high rates of fusion after surgery.[12-14,22,24] Both studies examining C1 anterior transoral osteosynthesis for unstable atlas fractures found 100% fusion rates and preserved or improved ROM.[14,22] Studies with patients receiving surgery involving C1 posterior polyaxial lateral mass screw-plate fixation or C1 posterior limited construct for unstable atlas fractures reported postoperative fusion in all patients.[12,13] Shatsky *et al*. found that 100% of patients undergoing posterior open reduction and internal fixation for C1 ring fractures attained fusion and the mean LMD decreased from 7.1 mm to 2.4 mm.[24] Both studies reporting fusion rate for surgically and conservatively managed patients found qualitatively superior fusion rates for surgically managed patients, one in patients with unstable atlas fractures and another for all atlas fractures.[18,21] However, poor fusion rates were noted for patients with atlas fracture of the lateral masses managed with surgery secondarily.[21]

Three studies examining conservative management found high fusion rates. A study examining fusion rates for patients managed with a halo vest found a fusion rate of 81.8%.[15] Kim *et al*. examined a cohort of patients with atlas fractures, of which 25 of 65 patients were unstable.[16] A total of 43 patients were treated with rigid collar, 18 with halo vest, and 4 surgically, and 54 of 65 patients demonstrated fusion.[16] Gehweiler Type 3 fractures, involving the posterior and anterior arches, were associated with instability and halo vest immobilization management.[16] Another study found that

Table 1: Studies examining diagnosis of isolated atlas fractures (original source)

Study	Authors, year	Study design	Level of evidence	Risk of bias	Country	Age, mean (range)	Sex, male (%)	Total *n*	Key findings
C1:C2 ratio is a potential tool assessing atlas fracture displacement and transverse ligament injury	Lin *et al*., 2019	Case series	IV	High	New Zealand	59.1	14 (58.3)	24	C1:C2 ratio >1.10 on radiograph had 80% sensitivity in predicting TAL injury
"Rule of Spence" and Dickman's Classification of TAL Injury Revisited: Discrepancy of Prediction on Atlantoaxial Stability Based on Clinical Outcome of Nonoperative Treatment for Atlas Fractures	Liu *et al*., 2019	Case series	IV	High	China	47.5 (21-69)	8 (61.5)	13	LMD >6.9 mm accurate in determining TAL injury but could not predict outcome of atlantoaxial stability after nonoperative treatment. Dickman's classification was more accurate in predicting outcome of atlantoaxial stability after nonoperative treatment
Radiologic criteria to predict injury of the TAL in unilateral sagittal split fractures of the C1 lateral mass	Park *et al*., 2019	Case series	IV	High	Korea	52 (32-69)	16 (61.5)	26	Total LMD >5.9 mm and unilateral LMD >4.3 mm could be associated with TAL injury in cases of unilateral sagittal split fractures

LMD: Lateral mass displacement, TAL: Transverse atlantal ligament

conservative treatment, via Philadelphia Minerva brace or soft collar, of atlas fractures resulted in an 80% fusion rate.[21]

Clinical outcomes

All four studies examining clinical improvement after surgery for unstable atlas fractures reported clinical improvement in all patients.[12-14,22] Five studies examined VAS pain scores.[12,17,18,22,24] Two studies reported improvement in VAS pain score in all patients after surgery.[12,22] Another study determined that the mean VAS pain score improved from 6.92 + 0.76 preoperatively to 2.08 ± 0.64 postoperatively in surgically managed patients and from 7.18 ± 0.75 to 2.91 ± 1.70 in patients managed with halo vest, with no difference between the groups.[18] One study determined that neck VAS pain score significantly decreased in patients with unilateral sagittal split fracture managed conservatively with the TAL intact but not those with TAL injury.[17] Shatsky *et al*. reported a VAS score of 0.7 at last follow-up.[24] Three studies reported improvement in ROM to physiologic levels after surgery for unstable atlas fractures,[12-14] while one reported improved ROM at 12 months with halo vest immobilization relative to posterior cervical fixation for unstable fractures.[18]

Radiographic outcomes

Four studies measured various radiographic values including LMD.[14,17,18,24] Kim and Shin determined that LMD significantly decreased after posterior C1 lateral mass screw–C2 pedicle screw fixation relative to halo vest immobilization.[18] Two studies utilizing surgical approaches of transoral osteosynthesis and posterior osteosynthesis determined that LMD decreased after surgery.[14,24] Kim *et al*. determined that LMD increased in patients with unilateral sagittal split fracture and TAL injury but did not change in those with TAL intact after conservative management.[17] Figure 2 represents a case example of an atlas fracture.

Complications

Four studies discussing complication rates reported common complications of venous plexus injury, screw displacement, errant screw placement, pseudoarthrosis, pneumopathy, thrombosis, cerebellar infarction, delirium, and additional neurologic complications in patients managed surgically and pin loosening or site infection, pseudoarthrosis, or death in patients managed conservatively.[13,18,21,24]

DISCUSSION

Isolated atlas fractures make up a considerable portion of upper cervical injuries, but presentation and management of such cases vary. We conducted a systematic review to characterize the literature describing the diagnosis and management of isolated atlas fractures. While previous literature reviews have been conducted,[2,9,25,26] the most recent systematic review on isolated atlas fractures was published in 2013. Since then, a number of new studies have been published. Of note, we would also like to recognize and further build on the recent recommendations published by the Spine Section of the German Society for Orthopaedics and Trauma in 2018.[25] We describe the role of diagnostic tools, such as the Rule of Spence, to underscore the importance of fracture characteristics including stability and type when determining the treatment strategy. Consideration of these factors will enable spine surgeons to care for patients with isolated atlas fractures more comprehensively.

Classification and diagnosis

Location of fracture and atlantoaxial stability are commonly used to classify atlas fractures and dictate management

Table 2: Studies examining management of isolated atlas fractures (original source)

Study	Authors, year	Study design	Level of evidence	Risk of bias	Country	Age, mean (range)	Sex, male (%)	Total *n*	Cohort characteristics	Conservative *n*
Self-designed posterior atlas polyaxial lateral mass screw-plate fixation for unstable atlas fracture	He *et al*., 2014	Case series	IV	High	China	43.5 (23-68)	16 (72.7)	22	Unstable atlas fracture (n=22)	NA
Function-preserving Reduction and Fixation of Unstable Jefferson Fractures Using a C1 Posterior Limited Construct.	Hu *et al*., 2014	Case series	IV	High	China	35.6 (20-60)	8 (66.7)	12	Unstable atlas fracture (n=12)	NA
Unstable Jefferson fractures: Results of transoral osteosynthesis	Hu *et al*., 2014	Case series	IV	High	China, USA	33 (23-62)	8 (66.7)	12	Unstable atlas fracture (n=12)	NA
Atlas and axis injuries role of Halovest	Kamal *et al*., 2014	Case series	IV	High	India	NA	NA	30 (11 with isolated atlas fracture)	Stable atlas fracture (n=11)	11
Management of Isolated Atlas Fractures: A Retrospective Study of 65 Patients	Kim *et al*., 2018	Case series	IV	High	USA	54.7 (16-90)	33 (50.8)	65	Unstable atlas fracture (n=25) Stable atlas fracture (n=40)	61
Clinical and radiological outcomes of conservative treatment for unilateral sagittal split fractures of C1 lateral mass	Kim *et al*., 2019	Retrospective cohort	II	Moderate	Korea	52 (32-69)	16 (61.5)	26	TAL intact (n=10) TAL injured (n=16)	26
Comparison of radiological and clinical outcomes after surgical reduction with fixation or halo vest immobilization for treating unstable atlas fractures	Kim *et al*., 2019	Retrospective cohort	II	Moderate	Korea	Conservative: 46.91±13.2 Surgical: 49.6±18.2	Conservative: 7 (63) Surgical: 8 (61.5)	24	Unstable atlas fracture (n=24)	11
C1 fracture: Analysis of consolidation and complications rates in a prospective multicenter series	Lleu *et al*., 2018	Prospective cohort	II	Moderate	France	60.5 (16-95)	35 (55.6)	63 (57 w/ isolated atlas fracture)	NA	40
Unstable atlas fracture treatment by anterior plate C1-ring osteosynthesis using a transoral approach	Ma *et al*., 2013	Case series	IV	High	China, USA	47.7 (23-68)	12 (60.0)	20	Unstable atlas fracture (n=20)	NA
A retrospective review of fixation of C1 ring fractures-does the TAL really matter?	Shatsky *et al*., 2016	Case series	IV	High	USA	43 (21-86)	9 (75.0)	12	Unstable atlas fracture (n=12)	NA

Study	Operative *n*	Type of surgery	Fusion (bone consolidation/ healing), *n* (%)	Clinical improvement, *n* (%)	VAS improvement, *n* (%)	Other outcomes	Complications	Rule of Spence used?	Classification System used?	Length of follow-up, months
Self-designed posterior atlas polyaxial lateral mass screw-plate fixation for unstable atlas fracture	22	C1 posterior polyaxial lateral mass screw-plate fixation	22 (100)	22 (100)	22 (100)	ROM: all well preserved Neurological status: all intact Operative time: 86 min (68-122 min) Blood loss: 28 mm (26-30 mm)	NA	No	NA	22.5±18.0
Function-preserving Reduction and Fixation of Unstable Jefferson	12	C1 posterior limited construct	12 (100)	12 (100)	NA	ROM: all patients recovered to preinjury level	Venous plexus injury during surgery: 1 (8.3) Screw displacement: 1 (8.3)	No	Landells	22 (6-40)

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Table 2: Contd...

Study	Operative *n*	Type of surgery	Fusion (bone consolidation/ healing), *n* (%)	Clinical improvement, *n* (%)	VAS improvement, *n* (%)	Other outcomes	Complications	Rule of Spence used?	Classification System used?	Length of follow-up, months
Fractures Using a C1 Posterior Limited Construct.										
Unstable Jefferson fractures: Results of transoral osteosynthesis	12	C1 anterior transoral osteosynthesis	12 (100)	12 (100)	NA	ROM: 35° (28-40) flexion; 42° (30-48) extension; 30° lateral bending to left; 28° lateral bending to right; 50° (35-72) rotation LMD: 7.0 mm (5-12 mm) pre to 3.5 mm (1-6.5 mm) post Difference in ADI between flexion and extension: 1.0 mm (1-3 mm) Blood loss: 300 mL (100-500 mL)	NA	No	Landells	16 (12-28)
Atlas and axis injuries role of Halovest	NA	NA	9 (81.8)	NA	NA	NA	NA	No	NA	12.18 (8-14)
Management of Isolated Atlas Fractures: A Retrospective Study of 65 Patients	4	NA	54 (83.1)	NA	NA	Failure to achieve fusion associated with age, motor vehicle accident as mechanism of injury, and Gehweiler Type 2 fracture No difference between those who attained fusion and those without fusion in ASIA, Frankel, or Nurick scores or LMD, ADI, BDI, or occiput-C2 angle	NA	Yes	Gehweiler	7.18
Clinical and radiological outcomes of conservative treatment for unilateral sagittal split fractures of C1 lateral mass	NA	NA	NA	NA	TAL intact: 4.7 pre to 2.1 post TAL injured: 6.8 pre to 4.7 post	LMD: TAL intact: 1.2 mm pre to 1.2 mm post TAL injured: 5.9 mm pre to 6.7 post Unilateral LMD: TAL intact: 1 mm pre to 1.1 mm post TAL injured: 4.3 mm pre to 4.7 mm post Atlanto-dens interval: TAL intact: 1.5 mm pre to 1.3 mm post	NA	No	NA	16 (12-47)

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Table 2: Contd...

Study	Operative n	Type of surgery	Fusion (bone consolidation/healing), n (%)	Clinical improvement, n (%)	VAS improvement, n (%)	Other outcomes	Complications	Rule of Spence used?	Classification System used?	Length of follow-up, months
						TAL injured: 2 mm pre to 3 mm post Basion-dental interval: TAL intact: 4.2 mm pre to 3.7 mm post TAL injured: 4.4 mm pre to 2.6 mm post Clivus-canal angle: TAL intact: 154.8° pre to 151.5° post TAL injured: 155.6° pre to 145.2° post Atlanto-occipital joint axis angle: TAL intact: 105.9° pre to 105.3° post TAL injured: 107.8° pre to 98.3° post Patient satisfaction: TAL intact: 80% TAL injured: 37.5%				
Comparison of radiological and clinical outcomes after surgical reduction with fixation or halo vest immobilization for treating unstable atlas fractures	13	C1-C2 fusion	Conservative: 8 (72.7) Surgery: 13 (100)	NA	Conservative: 7.18±0.75 pre to 2.91±1.70 post Surgical: 6.92±0.76 preoperative to 2.08±0.64 postoperative	Time-to-fusion: Conservative: 22.31±10.85 weeks Surgical: 14.91±3.9 weeks Mean reduction of LMD: Conservative: 0.97±2.69 mm Surgical: 3.21±1.21 mm Sum of lateral translation: Conservative: 9.37±1.18 mm pre to 8.4±2.09 mm post Surgical: 10.31±1.57 mm pre to 7.1±1.85 mm post Neck Disability Index: Conservative: 11.27±5.49 Surgical: 7.15±1.95 Patient satisfaction: Conservative: 30% (total n=10) Surgical: 76.9% (total n=13) ADI reduction: Conservative: 0.66±1.02 mm	Conservative: Pseudoarthrosis: 3 (27.3) Frequent pin loosening: 2 (11.2) Pin site infection: 1 (9.09%) Brain abscess: 1 (9.1) Surgical: Cerebellar infarction with unilateral vertebral artery occlusion: 1 (7.7)	Yes	Landells, Gehweiler	23.9 (15.5-37.3)

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Table 2: Contd...

Study	Operative *n*	Type of surgery	Fusion (bone consolidation/ healing), *n* (%)	Clinical improvement, *n* (%)	VAS improvement, *n* (%)	Other outcomes	Complications	Rule of Spence used?	Classification System used?	Length of follow-up, months
						Surgical: 1.47±1.08 mm ROM: Conservative: 7.0° (8.2°-17.8°) cervical curvature; 77.6° (54.3°-98.2°) C2-C7 ROM; 47.7° (32°-60.9°) C2-C7 flexion; 29.9° (22.1°-43.2°) C2-C7 extension; 61.5° (49.2°-71°) C1-C2 ROM; 28.9° (21.4°-36°) C1-C2 flexion; 32.5° (27.5°-39°) C1-C2 extension Surgical: 10.9° (3.1°-27.7°) cervical curvature; 61.57° (49.6°-72.3°) C2-C7 ROM; 30.3° (26°-33.9°) C2-C7 flexion; 31.2° (15.7°-41.2°) C2-C7 extension; 45.8° (34.8°-59.2°) C1-C2 ROM; 21.9° (16.3°-27.6°) C1-C2 flexion; 23.8° (18.5°-31.6°) C1-C2 extension				
C1 fracture: Analysis of consolidation and complications rates in a prospective multicenter series	23	Primary posterior C1-C2 fixation for C1 fx (n=11) Primary posterior C1-C2 fixation for C1-C2 fx (n=6) Secondary surgery (n=6)	Conservative: 32 (80.0) Primary surgery for C1 fx: 11 (100) Primary surgery for C1-C2 fx: 6 (100) Secondary surgery: 2 (33.3)	NA	NA	NA	Conservative: Death: 2 (5.0) Pneumopathy: 1 (2.5) Bed sores: 1 (2.5) Primary surgery: Pneumopathy: 2 (11.8) Thrombosis: 1 (5.9) Delirium: 2 (11.8) Neurologic: 2 (11.8) Internal fixation: 1 (5.9) Secondary surgery: Pneumopathy: 2 (33.3) Cardiac: 2 (33.3) Internal fixation: 1 (16.7)	Yes	Jefferson	6 weeks-1 year

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Table 2: Contd...

Study	Operative *n*	Type of surgery	Fusion (bone consolidation/ healing), *n* (%)	Clinical improvement, *n* (%)	VAS improvement, *n* (%)	Other outcomes	Complications	Rule of Spence used?	Classification System used?	Length of follow-up, months
Unstable atlas fracture treatment by anterior plate C1-ring osteosynthesis using a transoral approach	20	C1 anterior transoral osteosynthesis	20 (100)	20 (100)	20 (100) 6.0±1.3 pre to 1.3±1.0 post	ROM: 39.0°±12.0° at postoperative Operative time: 101.4±12.9 min (76-124 min)	NA	No	NA	48.5±20
A retrospective review of fixation of C1 ring fractures-does the TAL really matter?	12	C1 posterior osteosynthesis	12 (100)	NA	0.7±1.6 at last follow-up	LMD: 7.1 mm pre to 2.4 mm post ADI ≥4 mm at last follow-up: 0 (0) TAL injury on MRI: 11 (91.7)	Errant lateral mass screw placement: 1 (8.3) Occipital-C1 arthrosis: 1 (8.3)	No	Landells	17.3

VAS: Visual Analog Scale, ROM: Range of motion, LMD: Lateral mass displacement, NA: Not available, TAL: Transverse atlantal ligament, BDI: Basion-dens interval, ADI: Atlantodens interval

approach. Several classification systems are used to categorize atlas fractures based on location. The Jefferson classification divides atlas fractures into those of the posterior arch, anterior arch, anterior and posterior arches, and lateral masses.[27] The Gehweiler classification groups fracture into those of the posterior arch, anterior arch, anterior and posterior arches (distinguishing between stable and unstable), lateral masses, and transverse processes.[28] The Landells classification categorizes fractures based on those involving a single arch, both arches, and lateral masses.[7] In this review, studies most commonly utilized the Landells or Gehweiler classifications systems if stated.

Diagnostic rules such as the Rule of Spence and Dickman's classification are commonly utilized to predict atlantoaxial stability via determining the status of the TAL, a major stabilizer of the upper cervical spine. In particular, Dickman's classification recommends the use of MRI, which can evaluate for ligamentous injury via the presence of high-intensity signal, for identifying TAL disruption.[6,29] Of note, a further study in 2013 reinforced the utility of MRI over bony displacement measured on CT for detecting TAL injury (while we thought that these results were pertinent to mention, this particular study was not included in this review due to a majority of its patients presenting with combined C1 and C2 fractures).[30] Ultimately, evidence-based application of these diagnostic rules is unclear. The Rule of Spence was not universally used to guide the management of isolated atlas fractures in the studies included in this review. Meanwhile, Dickman's classification may be superior to the Rule of Spence in identifying TAL injury and predicting posttreatment stability after conservative management of atlas fractures.[20] Other heuristics have arisen, including a C1:C2 maximal width >1.10 as predictive of TAL injury[19] and a novel diagnostic rule for predicting TAL instability in unilateral sagittal split fractures.[23] Clearly, while Dickman's classification seems to be increasingly favored for identifying TAL disruption, the optimal classification system for isolated atlas fractures remains to be determined.

Stable atlas fractures

Stable atlas fractures, commonly those of the anterior arch or posterior arch, occur primarily as a result of axial compression in combination with flexion/extension forces.[27,31] Traumatic axial load, such as from motor vehicle accidents and falls on the head, is translated in the transverse plane towards the lateral masses.[27,31] The attachment points of the anterior and posterior arches to the lateral masses are weak points prone to fracture, thereby explaining the propensity of atlas fractures in these locations.[27,31] In contrast with unstable atlas fractures, stable fractures present with intact transverse

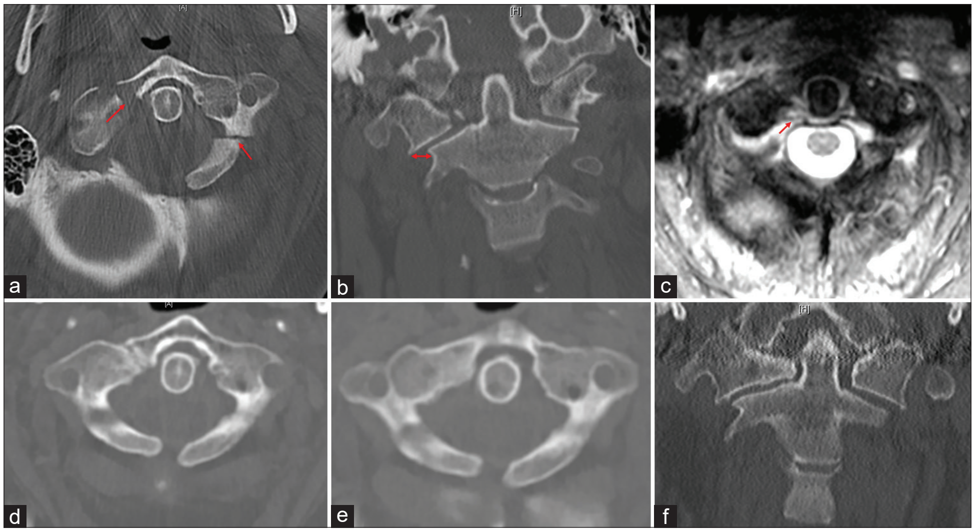

Figure 2: (Original source) A 68-year-old female who suffered a motor vehicle accident. She presented with neck pain and her neurological examination was normal. Axial CT scan showed a type 3 C1 fracture (arrows, a). Note the 6 mm "overhang" of C1 lateral mass over C2 facet on the coronal CT (arrow, b). Magnetic resonance imaging STIR sequence demonstrated transverse atlantal ligamentous disruption (arrow, c). The patient was treated with a rigid collar for 3 months. One-year follow-up CT shows partial healing of the fracture (d). A 2-year follow-up CT showed total healing of the fracture (e) with a stable lateral overhang (f). CT: Computer tomography

ligaments and cervical stability is preserved. Therefore, conservative techniques such as rigid or soft collars or halo immobilization have traditionally been sufficient to heal fractures and treat stable atlas fractures. Our systematic review indicates that high fusion rates can be attained with conservative management.[15,16,21]

Unstable atlas fractures

Jefferson burst fractures accompanied by injured transverse ligaments may require surgical approaches to ensure stability. Although halo vest management may sufficiently treat unstable atlas fractures,[16] spinal fusion is increasingly utilized and reported in studies due to possibly poorer functional and neurologic outcomes and greater complication rates with halo vest immobilization.[18] A recent study suggested that patients undergoing C1–C2 fusion have more favorable fusion rates, time-to-fusion, Neck Disability Index scores, and radiographical reduction in LMD than halo vest immobilization, possibly because of the greater control conferred by surgical techniques.[18] A variety of other surgical procedures have been proposed for unstable atlas fractures to contend with issues of stability and ROM. Atlas osteosynthesis may be applicable in cases of Jefferson burst fractures when ligament recovery is possible, with the possible benefit of preserving cervical ROM.[14,22,24] Other studies have proposed novel surgical techniques with favorable outcomes but remain limited by sample size and study numbers.[12,13]

A rare type of atlas fracture – a unilateral sagittal split fracture – presents unique management considerations including cervical instability. The initial case series reporting this condition described patients recovering from unilateral sagittal split fracture experiencing cock-robin deformity and requiring surgical fusion.[32] Therefore, unilateral sagittal split fractures may be classified as unstable. A study in this review further clarified that unilateral sagittal split fractures accompanied by TAL injury are associated with worse radiographical outcomes and non-significant VAS improvements than those without TAL injury after conservative management.[17] Early surgical treatment may, therefore, be considered in patients with unilateral sagittal split fracture with TAL injury to mitigate clinical deterioration.

Future directions

Larger scale prospective and retrospective studies are necessary to further guide management. Future studies should seek to develop more comprehensive, precise, and accurate classification systems and/or diagnostic rules for isolated atlas fractures by considering location, instability, and associated TAL injury in tandem. Studies should determine the optimal conservative management strategy for stable fractures. Future studies should also rigorously compare outcomes and complications between surgery and conservative management for unstable atlas fractures. Additional studies should examine patient-specific factors to allow for development of concrete management algorithms for patients with unstable isolated atlas fractures. These studies should report uniform outcomes including fusion rate, clinical outcomes such as VAS scores and ROM, and radiographic outcomes such as LMD in the same manner.

Limitations

There are several limitations in this study. Only published results with full-text manuscripts were included, placing results at risk for publication bias. Studies reporting low fusion rates for surgical management of atlas fractures may be underrepresented in the literature, leading us to overestimate the efficacy of the surgery for atlas fractures. In addition, the level of evidence was low, as most included studies were case series. No randomized trials were identified, although it is unlikely that a randomized trial could be conducted for this topic. The included studies were at high risk of bias due to retrospective nature and study design. Only studies written in or translated into the English language were included, perhaps excluding interventions well received in other regions. In addition, a variety of surgical approaches were utilized in the included studies, preventing us from determining which surgical approach may be associated with the greatest rates of VAS pain score or clinical improvement and under which circumstances different surgical approaches should be utilized. Heterogeneous outcomes were reported, preventing us from comparing a variety of outcomes across studies. Finally, no meta-analysis was conducted as part of this systematic review due to heterogeneity in reported outcomes and limitations in strength of data and sample size. Accordingly, although we could make assumptions from our analysis, we could not draw statistically significant conclusions. However, we present a robust review of the recent literature on isolated atlas fractures.

CONCLUSION

We present a systematic review of the diagnosis and management for isolated atlas fractures, highlighting the importance of instability and fracture type. Existing literature indicates that stable isolated atlas fractures may be treated conservatively with reasonable fusion rates and clinical and radiographic outcomes, while surgery is associated with high fusion rates and improved clinical and radiographic outcomes for unstable isolated atlas fractures. Future studies are necessary to further guide risk stratification and treatment approaches in management of the patients with isolated atlas fractures.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Matthiessen C, Robinson Y. Epidemiology of atlas fractures – A national registry-based cohort study of 1,537 cases. Spine J 2015;15:2332-7.
2. Kakarla UK, Chang SW, Theodore N, Sonntag VK. Atlas fractures. Neurosurgery 2010;66:60-7.
3. Teo EC, Ng HW. First cervical vertebra (atlas) fracture mechanism studies using finite element method. J Biomech 2001;34:13-21.
4. Gebauer M, Goetzen N, Barvencik F, Beil FT, Rupprecht M, Rueger JM, *et al.* Biomechanical analysis of atlas fractures: A study on 40 human atlas specimens. Spine (Phila Pa 1976) 2008;33:766-70.
5. Spence KF Jr., Decker S, Sell KW. Bursting atlantal fracture associated with rupture of the transverse ligament. J Bone Joint Surg Am 1970;52:543-9.
6. Dickman CA, Hadley MN, Browner C, Sonntag VK. Neurosurgical management of acute atlas-axis combination fractures. A review of 25 cases. J Neurosurg 1989;70:45-9.
7. Landells CD, Van Peteghem PK. Fractures of the atlas: Classification, treatment and morbidity. Spine (Phila Pa 1976) 1988;13:450-2.
8. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLoS Med 2009;6:e1000097.
9. Ryken TC, Aarabi B, Dhall SS, Gelb DE, Hurlbert RJ, Rozzelle CJ, *et al.* Management of isolated fractures of the atlas in adults. Neurosurgery 2013;72 Suppl 2:127-31.
10. Burns PB, Rohrich RJ, Chung KC. The levels of evidence and their role in evidence-based medicine. Plast Reconstr Surg 2011;128:305-10.
11. Sterne JA, Hernán MA, Reeves BC, Savović J, Berkman ND, Viswanathan M, *et al.* ROBINS-I: A tool for assessing risk of bias in non-randomised studies of interventions. BMJ 2016;355:i4919.
12. He B, Yan L, Zhao Q, Chang Z, Hao D. Self-designed posterior atlas polyaxial lateral mass screw-plate fixation for unstable atlas fracture. Spine J 2014;14:2892-6.
13. Hu Y, Xu RM, Albert TJ, Vaccoro AR, Zhao HY, Ma WH, *et al.* Function-preserving reduction and fixation of unstable Jefferson fractures using a C1 posterior limited construct. J Spinal Disord Tech 2014;27:E219-25.
14. Hu Y, Albert TJ, Kepler CK, Ma WH, Yuan ZS, Dong WX. Unstable Jefferson fractures: Results of transoral osteosynthesis. Indian J Orthop 2014;48:145-51.
15. Kamal Y, Ortho MS, Khan HA, Gani N, Haq AU, Gul S, *et al.* Atlas and axis injuries role of Halovest. Int J Health Sci (Qassim) 2014;8:335-45.
16. Kim HS, Cloney MB, Koski TR, Smith ZA, Dahdaleh NS. Management of isolated atlas fractures: A retrospective study of 65 patients. World Neurosurg 2018;111:e316-22.
17. Kim WJ, Park JB, Park HJ, Song KJ, Min WK. Clinical and radiological outcomes of conservative treatment for unilateral sagittal split fractures of C1 lateral mass. Acta Orthop Traumatol Turc 2019;53:402-7.
18. Kim MK, Shin JJ. Comparison of radiological and clinical outcomes after surgical reduction with fixation or halo-vest immobilization for treating unstable atlas fractures. Acta Neurochir (Wien) 2019;161:685-93.
19. Lin P, Chuang TC, Baker JF. C1:C2 ratio is a potential tool assessing atlas fracture displacement and transverse ligament injury. J Craniovertebr Junction Spine 2019;10:139-44.

20. Liu P, Zhu J, Wang Z, Jin Y, Wang Y, Fan W, *et al.* "Rule of Spence" and Dickman's classification of transverse atlantal ligament injury revisited: Discrepancy of prediction on atlantoaxial stability based on clinical outcome of nonoperative treatment for atlas fractures. Spine (Phila Pa 1976) 2019;44:E306-14.
21. Lleu M, Charles YP, Blondel B, Barresi L, Nicot B, Challier V, *et al.* C1 fracture: Analysis of consolidation and complications rates in a prospective multicenter series. Orthop Traumatol Surg Res 2018;104:1049-54.
22. Ma W, Xu N, Hu Y, Li G, Zhao L, Sun S, *et al.* Unstable atlas fracture treatment by anterior plate C1-ring osteosynthesis using a transoral approach. Eur Spine J 2013;22:2232-9.
23. Park HJ, Chang DG, Park JB, Kim WJ, Song KJ, Min WK, *et al.* Radiologic criteria to predict injury of the transverse atlantal ligament in unilateral sagittal split fractures of the C1 lateral mass. Medicine (Baltimore) 2019;98:e17077.
24. Shatsky J, Bellabarba C, Nguyen Q, Bransford RJ. A retrospective review of fixation of C1 ring fractures-does the transverse atlantal ligament (TAL) really matter? Spine J 2016;16:372-9.
25. Kandziora F, Scholz M, Pingel A, Schleicher P, Yildiz U, Kluger P, *et al.* Treatment of atlas fractures: Recommendations of the spine section of the German Society for Orthopaedics and Trauma (DGOU). Global Spine J 2018;8:5S-11S.
26. Mead LB 2nd, Millhouse PW, Krystal J, Vaccaro AR. C1 fractures: A review of diagnoses, management options, and outcomes. Curr Rev Musculoskelet Med 2016;9:255-62.
27. Jefferson G. Fracture of the atlas vertebra. Report of four cases, and a review of those previously recorded. BJS (Br J Surg) 1919;7:407-22.
28. Gehweiler JA, Osborne RL, Becker RF. The Radiology of Vertebral Trauma. Philadelphia: WB Saunders Company; 1980.
29. Dickman CA, Mamourian A, Sonntag VK, Drayer BP. Magnetic resonance imaging of the transverse atlantal ligament for the evaluation of atlantoaxial instability. J Neurosurg 1991;75:221-7.
30. Radcliff KE, Sonagli MA, Rodrigues LM, Sidhu GS, Albert TJ, Vaccaro AR. Does C_1 fracture displacement correlate with transverse ligament integrity? Orthop Surg 2013;5:94-9.
31. Sköld G. Fractures of the neural arch and odontoid process of the axis: A study of their causation. Z Rechtsmed 1978;82:89-103.
32. Bransford R, Falicov A, Nguyen Q, Chapman J. Unilateral C-1 lateral mass sagittal split fracture: An unstable Jefferson fracture variant. J Neurosurg Spine 2009;10:466-73.