Why you should wear your seatbelt on an airplane: Burst fracture of the atlas (Jefferson fracture) due to in-flight turbulence

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ABSTRACT

The Jefferson fracture is a burst-type fracture to the atlas first described in 1919, characterized by anterior and posterior fractures of the weak C1 ring caused by a sudden axial load to the vertex of the skull. Here we report a Jefferson fracture caused by head trauma due to mid-flight turbulence in an unrestrained 56-year-old male airline passenger. Imaging revealed a comminuted burst fracture of the atlas with an avulsion fracture of the transverse atlantal ligament. The patient was treated conservatively in a Miami-J collar with close clinical and radiographic follow-up. Lateral flexion-extension radiographs demonstrated fracture stability, and clinically the patient lacked pain or neurologic symptoms at 12 weeks from injury. To our knowledge this is the first report of a Jefferson fracture caused by axial compression attributable to in-flight turbulence. Traditionally associated with automobile crashes and diving headfirst into shallow pools, the axial load results in a compressive force to the atlas and subsequent lateral separation of the two halves of the C1 vertebral ring. The purpose of this case study is to alert providers, aircraft personnel, and passengers of the inherent risk of air travel and the importance of wearing a seatbelt at all times, describe the signs and symptoms of this often-overlooked fracture, and provide general treatment guidelines based on radiographic assessments of fracture stability.

1. Introduction

Commercial airline travel has become increasingly utilized around the world, and despite it being deemed the safest and fastest mode of transportation, air travel does not come without inherent risks, the most common of which is air turbulence. Causes of turbulence can be broken down into mechanical, convective, and wind shear.¹ Even with the FAA-mandated implementation of airborne wind shear detection and alert systems in all aircraft and air traffic control centers after 2 January 1991,^{2,3} commercial flights still run a high risk of encountering wind shear, termed “clear-air turbulence”. Unlike mechanical and convective causes, wind shear is the most insidious turbulence type and not associated with any grossly visible weather pattern. This type of turbulence is particularly dangerous and often encountered either just prior to landing and/or after takeoff. With sufficient severity, wind shear can result in fatal accidents, such as the 37-fatality crash of USAir Flight 1016 in 1994 and the 260-fatality crash of American Airlines Flight 587 in 2001.^{4,5} Even without crashing, unrestrained passengers could potentially be displaced from their seats, causing significant injury within the airline cabin.^{6,7}

First described in 1919 by Geoffrey Jefferson,⁸ the C1 burst fracture

bearing his namesake is characterized by fractures of both the anterior and posterior arches of the C1 vertebra. The mechanism of injury is usually a sudden axial load to the vertex of the skull such as diving into shallow water or impacting the roof of a car.^{9,10} The axial load is transmitted through the skull to the occipital condyles, where it is met by the counter-force of the occipital spine at the atlas. Due to the up-sloping nature of the atlanto-occipital articular facets, the two halves of the atlas yield to the axial force by sliding laterally, resulting in fracture lines classically occurring in four locations: anteriorly and posteriorly on both sides of the weak C1 ring.^{9,10}

The clinical presentation of a Jefferson fracture is often nonspecific and may include transient unconsciousness and/or neurological symptoms that do not often involve damage to the spinal cord.^{9,10} Given the forces required to produce a Jefferson fracture, however, it is reasonably expected that other cervical injuries accompany this fracture type, with comorbid axis fractures reported in approximately one-third of cases.¹⁰ The diagnosis is often missed due to its nonspecific presentation and inadequate imaging of the occipito-cervical junction. With a high clinical suspicion in the context of a classic mechanism of injury, an open-mouth odontoid plain film is the imaging modality of choice for both making the diagnosis as well as assessing fracture stability.^{11,12}

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Additional CT and MRI imaging may aid in characterizing the fracture pattern, assessing for other cervical injuries, and visualizing the transverse ligament.¹⁰

Management of Jefferson fractures is largely dependent on the integrity of the transverse ligament. An intact ligament is by definition a stable fracture warranting more conservative treatment, whereas visibly separated lateral masses imply a compromised transverse ligament and traditionally implied an unstable fracture.^{12–14} The treatment of choice for stable fractures is a hard cervical collar for three months, whereas unstable injuries beget more invasive, prolonged, and controversial treatment modalities including but not limited to cranial traction and cervical spine fusion.^{12,13} The prognosis, with appropriate limitations of activity and compliance with immobilization therapy, is generally excellent.^{9–13,15,16}

While there have been various documented causes of cranial injuries resulting in Jefferson fractures, there have been no prior studies exploring this fracture type and associated spinal injuries sustained specifically due to in-flight turbulence. An impact of the skull on the overhead compartment could reproduce the axial compression injury mechanism commonly associated with Jefferson fractures. In this study we describe a case of this exact mechanism due to mid-air turbulence.

2. Case report

A 56-year-old male ship-builder with no significant past medical history presented to a Level I Trauma Center in Florida (Jackson Memorial Hospital) for an evaluation of a neck injury sustained on a flight from Rio de Janeiro, Brazil to Miami, Florida. The plane encountered mid-air turbulence, causing the unbelted patient to elevate from his seat and strike the apex of his head on the overhead storage bin of the aircraft. On arrival the patient was in a hard cervical collar and reported vague neck pain, but no numbness or tingling in his upper or lower extremities. Physical exam revealed minimal tenderness to palpation at the midline of the upper cervical spine, and no other areas of tenderness along the remainder of the cervical, thoracic, and lumbar spine. Motor and sensory function was normal in both upper and lower extremities bilaterally, and all extremities were well perfused with intact pulses. There were normal reflexes in bilateral upper and lower extremities with no signs of myelopathy. The patient reported a previous lower lumbar spine injury while surfing approximately 10 years ago that was managed conservatively and denied any radicular or myelopathic symptoms. The patient had no other complaints at the time of presentation.

X-rays and CT scan obtained in the emergency department demonstrated a comminuted burst fracture of the C1 vertebral body, involving the anterior and posterior arches on the left, and the posterior arch on the right (Fig. 1 and Fig. 2a). A left-sided avulsion fracture of the transverse atlantal ligament from the lateral mass was also identified (Fig. 2a). The transverse foramina were spared. The atlantodental interval, appeared stable at 3 mm (Fig. 2c). There was a comminuted fracture of the left lateral mass (Fig. 2b) with lateral overhang of C1 on C2 measuring 5 mm on the left and 4.5 mm on the right. MRI demonstrated edema surrounding the fractures (Fig. 2d–f) and increased signal

suggesting sprains of the left alar and C1–C2 interspinous ligaments. The constellation of findings suggested an unstable fracture.

With concern for instability, surgical stabilization was recommended. However, the patient elected to pursue non-operative treatment despite the risks. The patient was therefore treated in a rigid Miami-J cervical collar at all times, received symptomatic pain control, and hospitalized for close neurologic monitoring over the next 24 h. He was discharged the following day when we confirmed that neurologic exam remained stable and pain was controlled.

At his 1-, 2-, and 4- week follow-up appointments, the lateral mass overhang of C1 on C2 appeared stable at 9.5 mm (Fig. 3a–c) and atlantodental interval appeared stable at 3 mm on lateral radiographs (Fig. 3d–f). A CT scan at 9 weeks from injury demonstrated that the fracture fragments were largely unchanged in position as compared to the injury CT scan (Fig. 4). Flexion-extension radiographs at the 12- and 14-week visit did not demonstrate instability and showed some interval fracture healing (Fig. 5). Clinically, at 12 weeks the patient had some improving neck stiffness, but otherwise no neck pain, weakness, sensory deficits, or bowel or bladder problems and was permitted to begin weaning the cervical collar as tolerated. These findings were identical at the 14-week follow-up.

3. Discussion

Jefferson fractures (C1 burst fractures) are primarily caused by axial compression to the occiput. We present a case of a patient who sustained an unstable Jefferson fracture as a result of an axial compression force to the occiput during in-flight airplane turbulence, which has never before been described. Atlas fractures are often associated with other fractures, such as odontoid fractures, in which case the concomitant injury determines the treatment strategy.¹⁷ However, isolated atlas fracture treatment is controversial.

Criteria for instability is important to establish to help guide treatment of atlas fractures. The rule of Spence is often cited as a criterion for instability. The rule of Spence states that the overhang of the lateral aspect of C1 on C2 of more than 6.9 or 8.1 mm suggests instability (the difference in the numbers are attributable to the magnification effects of radiographs).^{14,18} Another criterion for instability of atlas fractures is widening of the anterior atlantodental interval to greater than 3 mm. These two measures of instability suggest failure of the strongest stabilizer of the atlantoaxial joint – the transverse atlantal ligament.

An important consideration in treating Jefferson fractures is the type of injury to the transverse ligament, if present, as suggested by Dickman et al.^{12,19} Dickman Type I injuries (intrasubstance ligamentous ruptures) are believed to lack the potential for healing and are thus treated operatively. However, Dickman Type II injuries (bony avulsion fractures of the transverse ligament) have the potential for bony healing with immobilization.

In our case, the patient sustained a Jefferson fracture of the atlas with an avulsion fracture of the transverse ligament (Dickman Type II). Due to the unstable characteristics of the injury and high risk of displacement, operative intervention was recommended. The patient understood these risks, but elected to proceed with non-operative

Fig. 1. a. Anteroposterior open-mouth radiograph of the cervical spine on day of injury that is inadequate for measuring lateral overhang of C1 on C2 due to metal fillings in teeth obscuring complete view. b. Fracture of the atlas in image “A” outlined in red for clarity. c. Lateral view of the cervical spine on day of injury, in which the fracture of the posterior atlas may be appreciated (arrow).

Fig. 2. Injury CT scan (a–c) and MRI (d–f) of the cervical spine. A. Axial view at the level of C1 demonstrating fractures of the left anterior ring, both sides of the posterior ring, and an avulsion fracture of the left side of the transverse atlantal ligament (arrow). B. Coronal view demonstrating a comminuted fracture of the left lateral mass complex with overhang of C1 on C2. C. Sagittal view of the atlantodental interval with 3 mm of gapping. Also visualized is an ossicle or fibrous union of an old fracture of the inferior aspect of the atlas anterior to the dens. d–f. Axial views at the level of the atlas demonstrating an avulsion fracture with edema of the left side (arrow) of the transverse atlantal ligament (highlighted in red).

Fig. 3. Anteroposterior open-mouth and lateral cervical spine radiographs at 1 week (a,d), 2 weeks (b,e), and 4 weeks (f,g) following injury. Note that the position of the fracture fragments are unchanged and the atlantodental interval is well maintained at 3 mm. Also, note that the lateral overhang of C1 on C2 (brackets) remains stable at 9.5 mm.

Fig. 4. CT scan of the cervical spine 9 weeks out from injury. a–e. Sequential axial views demonstrating healing fracture fragments with fragment position that is largely unchanged from the injury imaging studies seen in Fig. 2. F. Sagittal view showing an atlantodental interval of 3 mm, unchanged when compared to earlier studies in Fig. 2.

treatment in a hard cervical collar and close follow-up. The patient went on to heal with slight neck stiffness, but otherwise without any pain or other complications.

There is a paucity of literature describing conservative treatment of unstable Jefferson fractures. Haus et al. describe a case of a 62-year-old male who sustained a Jefferson fracture after a fall from standing height.²⁰ After a delay of 5 days, the patient presented to a chiropractor who did not identify the fracture on cervical spine radiographs and performed a manipulation. With repeat x-rays the following day, the chiropractor identified a cervical spine fracture and the patient was transferred to the author's hospital in which open mouth views

demonstrated lateral mass overhang of 14 mm and CT scans demonstrated a Jefferson fracture with bony avulsion of the transverse ligament. These findings are similar to our patient's fracture characteristics, which are consistent with an unstable Jefferson fracture. The authors note that the patient in their case had an atlantodental interval of 3 mm that was stable with no motion on lateral flexion-extension views. The patient declined surgical treatment or halo vest immobilization. Therefore, the patient was treated with a Miami J cervical collar with monthly clinical evaluations, quarterly CT scans, and flexion-extension radiographs at 6 months and 1 year post-injury. The patient was weaned out of his collar at 3 months post-injury and began neck

Fig. 5. Neutral, flexion, and extension lateral radiographs of the cervical spine at 12 weeks (a–c) and 14 weeks (d–f) after injury. The atlantodental interval and space available for spinal cord distance appears stable and the posterior ring of the atlas appears healed at 14 weeks.

mobilization as tolerated. At 1 year, he had no pain and slight stiffness in the neck. Flexion-extension radiographs showed complete healing of C1 without any subluxation.

Critics of nonsurgical management by immobilization with a hard cervical collar cite high nonunion rates and posttraumatic pain. They therefore advocate for more aggressive treatment of unstable Jefferson fractures with halo vest immobilization and/or open surgical treatment. Halo vest immobilization offers stability and alignment through ligamentotaxis.^{10,21–23} However, there are many complications of the halo/vest technique including pin site infection, pin site loosening, and persistent instability, to name a few.²⁴ Therefore, many surgeons advocate for reduction and internal fixation of unstable Jefferson fractures.^{11,25–30}

There are various surgical options for treating unstable atlas fractures. Kesterson et al. advocate for occipitocervical fusion of Jefferson fractures with iliac crest bone graft.¹¹ However, this type of fixation significantly limits occipitocervical motion. Therefore, several authors advocate for C1–C2 fixation techniques.^{25,26} Others advise osteosynthesis of the atlas to preserve greater cervical spine mobility while maintaining anatomic reduction and healing of the fracture.^{27–30}

While we cannot make a recommendation to treat all unstable Jefferson fractures nonoperatively, in this patient, the presence of an avulsion fracture associated with the transverse ligament provided the potential for healing and restoration of stability without surgical intervention. It is important to evaluate the stability and healing potential of the fracture both radiographically and clinically before making a treatment decision.

In conclusion, the patient presented in our case report may have avoided such a serious Jefferson fracture injury by simply wearing his seatbelt on the airplane. Turbulence during a flight may occur suddenly and at any moment during the flight. Therefore, the safest way to avoid this problem is to be seated with a seatbelt securely fastened throughout the duration of the flight.

4. Declaration of interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jor.2019.06.019>.

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