Technical Considerations in Surgical Fixation of Jefferson Fracture

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Abstract

Keywords
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► biomechanics
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► lateral displacement
► rule of spence
► transverse atlantal ligament

Jefferson fracture is defined as the simultaneous disruption of the continuity of the anterior and posterior arches of the atlas vertebra. It generally results from an axial impact to the head. Most of these fractures are amenable to nonoperative management. Significant disruption of the transverse atlantal ligament that is the main stabilizing ligament of the atlantoaxial articulation and contiguous spinal injuries often form the indications for operative intervention in these fractures. The outward and caudal displacement of the C1 lateral masses observed in these fractures often requires significant deviation from the standard operative technique of atlantoaxial fixation when the osseous elements are intact. Accordingly, we have described the surgical nuances relevant to the exposure and instrumentation of the atlantoaxial region in the setting of Jefferson fracture, through our experience in two cases.

Introduction

Jefferson fracture, defined by the disruption of the ring of the first cervical vertebrae, infrequently requires operative intervention.[1,2] Most of these fractures are amenable to conservative management, commonly limited to stabilization through a semirigid /rigid orthotic device.[1,2] Consequently, there is scanty literature on the operative strategy and practical difficulties encountered when the surgical fixation of these fractures is planned. Often the operative plan must take into account associated osseo-ligamentous injuries in the region of craniovertebral junction (CVJ) which create an indication for surgical fixation of these fractures.[3] Other concomitant vertebral fractures should also be considered while making the surgical plan.[4–7] Since the spinal canal is quite capacious at the level of the atlas vertebra (C1), neurological injury is uncommon in isolated atlas fractures. However, the treatment plan must take into account the expected physiological loading of an injured spine in a neurologically intact patient. In this series of two cases of Jefferson fracture, we have discussed the common practical challenges faced by the surgeon in the exposure and instrumentation of the lateral masses (LMs) of the atlas, when the surgical fixation for these fractures is planned.

Injury Mechanism and Pathological Anatomy

Though the etiologic mechanism of ring disruption in atlas fractures is well known, a review of the pertinent injury mechanism and relevant biomechanics is expected to provide an improved understanding of the observed pattern of displacement of the fracture fragments and the appropriate surgical strategy.

Atlas fractures are classically sustained as either a hyperextension or axial compression injury associated with motor vehicle accidents or sports-related mishaps (shallow diving, hard tackles, etc.) involving a "head first" collision.[1,8] The sudden axial loading of the cervical spine translates to radial distractive forces upon the atlas ring (►**Fig. 1**) due to the sloping surface of the atlantoaxial
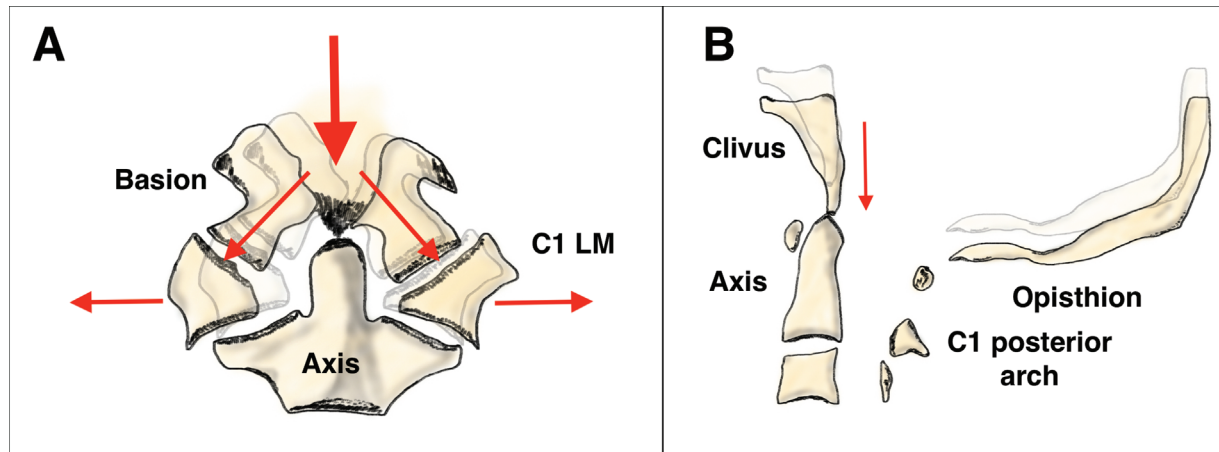
Fig. 1 Schematic diagram in coronal (**A**) and sagittal (**B**) perspective showing the force vector due to the traumatic impact and weight of (bold red arrow) the head (axial loading) that causes the lateral displacement of the C1 lateral masses (LMs) (small red arrows).

articulation.[1,9] Isolated posterior arch fractures of the atlas may result from the pinching of the posterior arch between a hyperextended occiput and C2 spinous process.[1,10] High-speed impact leads to classic burst fracture and slow speed trauma leads to LM fractures. These fractures correlate directly to osteoporosis.[9]

The atlantoaxial joint contributes nearly 50% to the observed range of neck rotation.[11] Due to the contrasting demands posed by requirements of rotational freedom and resilience of craniocervical articulation, ligaments have a disproportionate role in stabilizing this region of the cervical spine as compared with the shape of articular surfaces.[11] The main ligaments responsible for atlantoaxial stability are the transverse atlantal ligament (TAL) as the primary stabilizer (resists translation in sagittal plane) and the paired alar ligaments and capsular ligaments as secondary stabilizers (resist rotation).[12–14] The TAL is the thickest and strongest ligament of all the ligaments at CVJ.[12,15,16] Hence, in the event of TAL incompetence, other weaker ligaments (tectorial membrane, apical ligament, capsular ligaments, atlantoaxial and atlantooccipital ligaments) are deemed to fail leading to atlantoaxial instability.

When the TAL fails in conjunction with the disruption of the anterior and posterior atlantal arches, the radial forces pushing the atlantal LMs apart during axial loading are unopposed. This leads to lateral displacement (LD) of the atlantal LMs that "overhang" the lateral margin of the superior facet of the axis vertebra (C2) (►**Fig. 1**), Spence et al observed through their biomechanical experiments that an aggregate bilateral LM overhang of more than 6.9 mm is suggestive of TAL failure Rule of Spence.[15] Dickman et al further classified TAL injury into two types based on substance injury or bony avulsion injury that had a significant impact on management of these injuries.[3,12] They also showed the magnetic resonance imaging (MRI) characteristics of anatomically and physiologically incompetent TAL. However, later studies have questioned the validity of the "Spence rule" in predicting the integrity of the TAL.[17–19] The TAL may be disrupted even with intact arches that prevent the LD but nevertheless leads to atlantoaxial instability. Recently, a C1:C2 ratio (ratio of distances between C1 LM and C2 LM) more than 1.11 has been proposed to have high sensitivity and specificity to predict TAL injury.[20]

The LD of the LMs of the atlas continues till the basion contacts the odontoid process and the weight of the head is now transmitted through this contact point. A precarious stability is restored at this juncture (►**Fig. 1**).

The need for surgical treatment of atlas fractures is primarily dictated by evidence of ligamentous injury or other associated destabilizing injuries of the adjacent spine. The most commonly performed fusion for atlas fractures is an atlantoaxial fixation using a Goel Harms technique (►**Fig. 2C**). An occiput to C2 fusion is another less favored alternative as it sacrifices the physiological mobility between occiput and atlas. Indications for occipitocervical fusion arise with anomalous vertebral arteries (VAs), fractured C1 LMs, significant deformity/torticollis at CVJ, etc.[21]

Illustrative Cases

Case 1

A 33-year-old female suffered multiple skeletal injuries after sustaining a fall from height. She had cervical and dorsal spine injury, left supracondylar humerus fracture, and bilateral distal end of radius fractures. Neurologically she was determined to be American Spinal Injury Association (ASIA)-A (D6 clinical level). Plain computed tomography (CT) spine showed a classic Jefferson fracture (Landells type 2) with a C1 to 2 overhang of more than 7 mm suggesting a TAL injury along with a D4 to 5 burst fracture. MRI showed an uninjured spinal cord at CVJ with severe cord compression at D4 to 5 level and cord edema. The patient was planned for posterior C1 to 2 fusion and 360-degree fusion for dorsal level. C1 LM and C2 pars screws were placed and a transverse connector was used to restrain the lateral translation of C1 LMs over C2 facets. The dorsal spine injury required D4 to 5 transpedicular corpectomy and D3 to 7 pedicle screw fixation with anterior mesh cage placement (►**Figs. 3–4**).
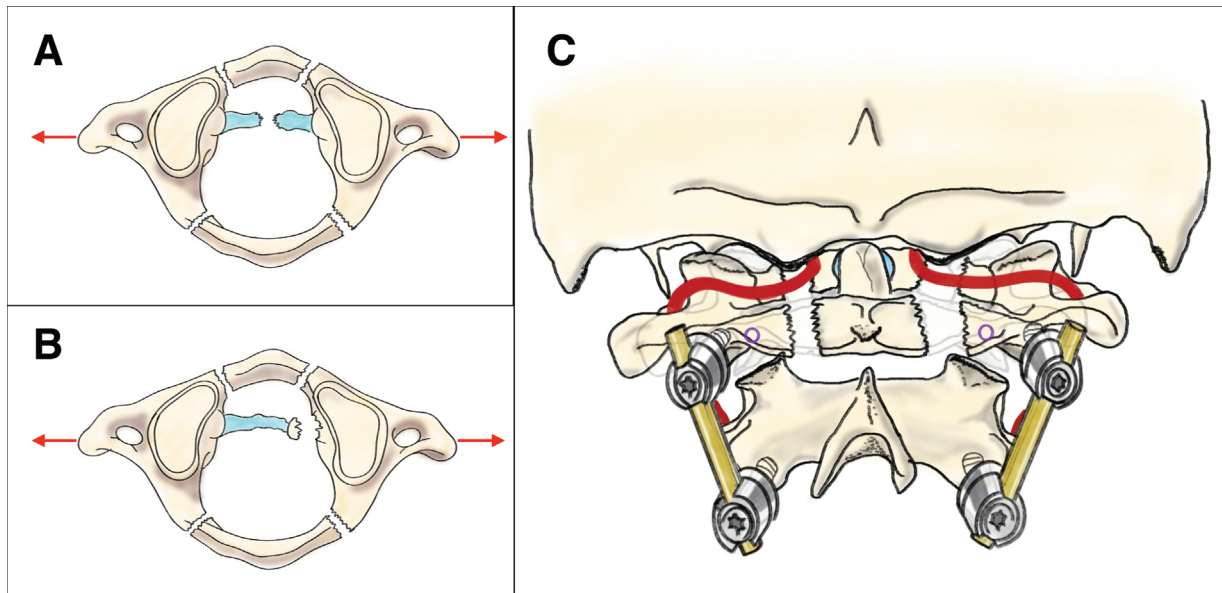
Fig. 2 Schematic diagram showing Gehweiler type 3B type 1 (**A**) and 3B type 2 (**B**) fractures showing disruption of the transverse atlantal ligament in the latter. (**C**) The C1 to 2 lateral mass and screw fixation of type 3 fractures highlighting the lateral than usual trajectory (violet circles) needed for C1 lateral mass screws.

Case 2

A 35-year-old male sustained a neck injury after he met with a road traffic accident. He was neurologically intact (ASIA-E). He presented after 1 year with complaints of neck pain and episodes of transient weakness. Dynamic scans showed a reducible atlantoaxial subluxation with a step in the spinolaminar line. Noncontrast CT CVJ showed a classic Jefferson burst fracture with fractures of both anterior and posterior arches (Landells type 2). MRI confirmed TAL injury (Gehweiler type 3a) without any imaging evidence
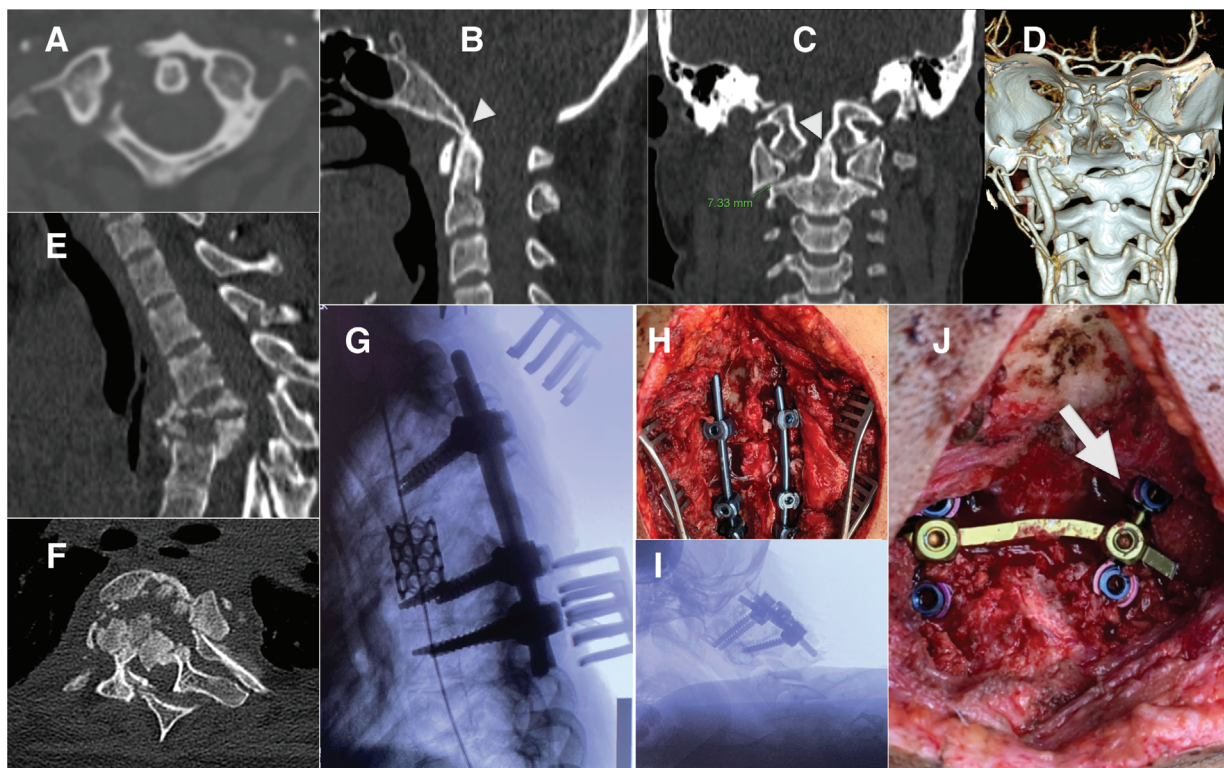

Fig. 3 Case 1 imaging (**A–D**) showing atlas arch fracture in various planes of imaging, pronounced overhang of the C1 lateral mass (LM) (**C**) and resultant caudal displacement of the basion impacting upon the odontoid tip (white arrowheads (**B**). (**E–H**): Coexisting dorsal spine injury (D3 burst fracture) requiring anterior column reconstruction and pedicle screw fixation. (**I**): Lateral intraoperative X-ray image of the C1 to 2 fixation. (**J**) Intraoperative image of C1 to 2 fixation showing the significant lateral displacement of the right C1 LM (white arrow).

Fig. 4 Positioning of case 1: Prone position with head fixed in 3-pin clamp in neutral position.

of injury to the spinal cord. Patient was planned for posterior C1 to 2 fusion. C1 LM and C2 pars screws were placed bilaterally. Residual atlantoaxial dislocation was reduced by pushing the posterior arch of C2 ventrally and rods were fixed bilaterally. Bone graft placed for augmenting fusion. Patient had an uneventful recovery and was discharged after 4 days. His neck pain improved at 3 months follow-up (►**Fig. 5**).
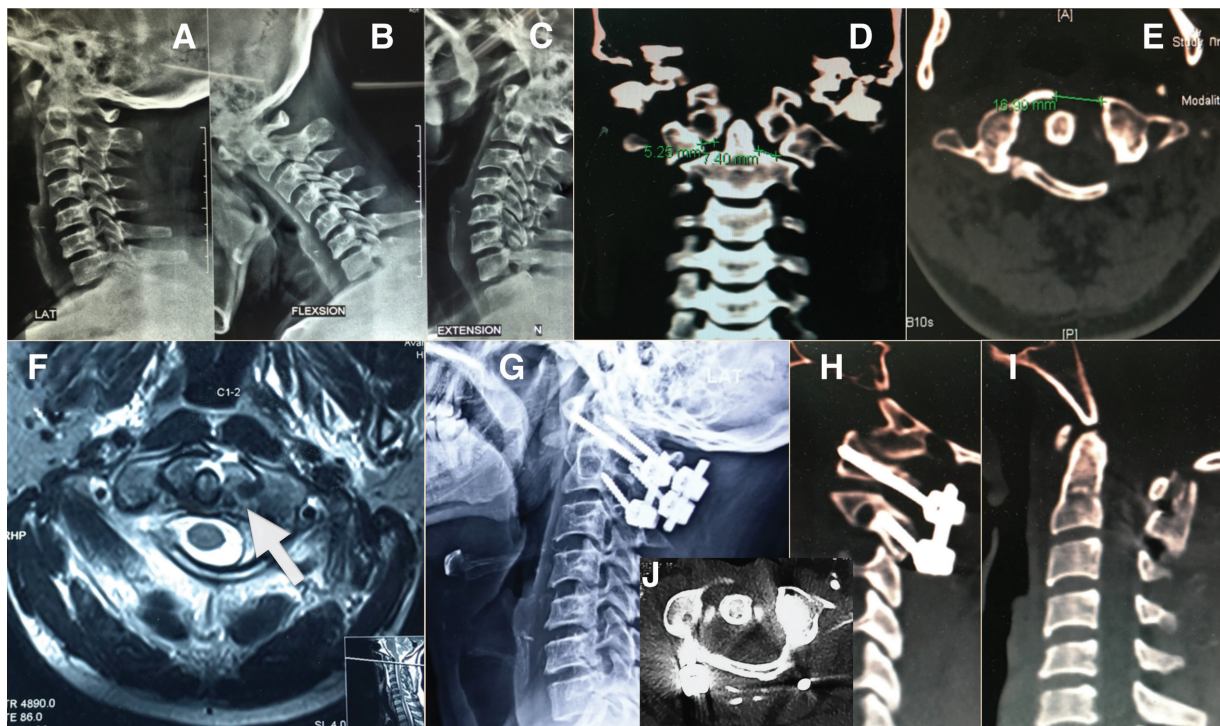

Fig. 5 Case 2 imaging (**A–E**): Dynamic cervical X-ray and computed tomography imaging showing the atlas arch fractures. Increase in atlantodental interval is noted in flexion. (**F**) T2 axial magnetic resonance imaging showing transverse atlantal ligament disruption (white arrow). (**G–J**) C1 to 2 fixation.

Technical Considerations during C1 to 2 Fusion for Atlas Fractures

Positioning and Surgical Exposure

We prefer to position the patient on a radiolucent spine table with the head held rigidly in a 3-pin skull clamp and the chin very slightly flexed upon the neck (modified military tuck). The table is then tilted to elevate the head end by approximately 20 to 30 degrees (reverse Trendelenburg position). This allows the body weight to provide traction, reduce the fracture, and decrease venous congestion in the perineural venous plexus, aiding the exposure of atlantoaxial joints.

The dorsal exposure of the upper cervical spine and occiput is familiar to spine surgeons. The midline incision is deepened along the midline avascular plane of the ligamentum nuchae, till the posterior tubercle of the atlas and the robust, bifid C2 spinous process is exposed.

Several important observations in the context of atlas fractures must be kept in mind to avoid inadvertent injury to important neurovascular structures during exposure of the C1 LMs and atlantoaxial joints. When the anterior and posterior atlantal arches are fractured, the freely floating C1 LM is situated often deeper and more laterally in the operative field than its expected anatomical position. The sulcus arteriosus harboring the VA may be more caudal than anticipated placing the VA at risk. Hence, a safer strategy is to expose the bony elements in a caudocranial direction when the dissection is being performed away from the midline. The C2 laminae are followed cranially with elevation of the soft-tissue in subperiosteal plane to reach the upper surface of the C2 facets.

Preganglionic sectioning of the C2 nerve root may be necessary in the presence of grossly displaced C1 LM for ease of dissection. However, we prefer to denude the C2 nerve root by coagulation and division of the venous plexus around the root. During this step, care must be taken to avoid perforating the venous plexus that may lead to disconcerting venous bleeding and it may be required to pack the space with a gelatin sponge for achieving hemostasis.

In partially healed fracture, callus formation at the fractured ends of the posterior arch can obscure the anatomical landmarks and confuse the surgeon. A careful study of the preoperative CT is needed to exclude this eventuality.

C1 Lateral Mass Screw Insertion

In acute fractures, the floating C1 LM may need stabilization by an assistant during preparation of the screw tracks. The assistant holds the posterior arch fragment attached to the LM with a towel clip, while a powered drill is used to decorticate the screw entry point. The hand drill can then be used to develop the track further. It is preferred to use the motorized drill to avoid anterior slippage of unstable C1 LM due to the pressure applied during drilling. Conventionally, when the atlas is anatomically intact, the anterior tubercle helps to guide the screw trajectory in the sagittal plane under

lateral X-ray visualization. However, this landmark is unreliable when the arches are disrupted. Hence, the C1 LM screw in these cases must be inserted parallel to the inferior surface of the C1 LM that is visualized upon opening the atlantoaxial facet joints. In the axial plane, a slightly medial screw trajectory must be maintained to avoid VA injury.

The overhang of the posterior arch upon the C1 LM must also be drilled to avoid being forced into an excessively cephalad trajectory into the atlanto-occipital joints. A bicortical screw is preferred in these cases. The LM dimensions must be measured on preoperative CT scans to determine appropriate screw length. Excessively long screws can put the internal carotid artery and hypoglossal nerve at risk anterior to the LMs. The screws must be directed medially by approximately 8 to 10 degrees to avoid the VA foramen laterally.

In cases, where the LMs are comminuted, the surgeon may be left with no choice than to include the occiput in the fusion.

Discussion

Sir Geoffrey Jefferson, in 1920, studied 42 cases of atlas fractures described in literature and included 4 of his own to devise a classification scheme for these injuries.[1] He later described a four-part fracture of the atlas detailed earlier in autopsy studies of Vincenzo Quercioli, an Italian surgeon.[22] This particular configuration of atlas fracture bears his name today.

A more modern classification of atlas fractures[23] and TAL injuries[3,12] is described in ►**Table 1** and ►**Fig. 2A** and **B.**

Atlas fractures constitute up to one-sixth of cervical spine fractures and around 1% of all spinal column injuries.[25] Understandably, bony injuries of the atlas heal satisfactorily with immobilization but concurrent or isolated ligamentous injuries do not heal well. Hence, the protocol for the management of atlas fractures is critically influenced by the presence and nature of the ligamentous injury.

Prior to the advent of MRI and high-resolution CT scanners, altered osseous relationships reflected in standard X-ray exposures were taken as indirect evidence of ligamentous disruption. In relation to atlas fractures, the most relevant of these X-ray findings is the "Spence rule Rule of Spence."[15] According to this rule, 7 mm or more of aggregate overhang of C1 LM beyond the C2 facets is indicative of failure of the TAL. However, recent studies have strongly questioned the reliability and significance of this radiological sign.[18,19] Spence et al had made his observations based upon an isolated atlantoaxial complex stripped of supportive tissue and muscle. He created artificial fractures in the arches of the atlas vertebra simulating a Jefferson fracture and mechanically distracted the C1 LMs. He determined that a displacement beyond 6.9 mm was always associated with a torn TAL. However, recent studies, encompassing cadaveric experiments and in vivo observations, have produced a wide range of LD of C1 LM

Table 1 Classifications of Atlas fracture

| Landells-Van Peteghem classification[2]	
• Type 1	Fracture of either anterior or posterior arch
• Type 2	Classic burst fracture (both arches)
• Type 3	Primarily lateral mass fracture extending into one arch only
Gehweiler classification[23,24]	
• Type 1	Fracture of the anterior arch
• Type 2	Fracture of the posterior arch, usually bilateral
• Type 3	Fractures involving the anterior and posterior arch (classic burst fracture)
o Type 3a	Intact TAL
o Type 3b	Disrupted TAL
■ Dickman type 1	Ligamentous disruption of TAL
■ Dickman type 2	Bony avulsion fracture of TAL
• Type 4	Fracture of the lateral mass
• Type 5	Isolated fracture of C1 transverse process

Abbreviation: TAL, transverse atlantal ligament.

that can be conclusively associated with TAL failure, calling into question the entire point of defining a single radiological measure to predict ligamentous injury.[26,27]

Direct visualization of the TAL through proton density MRI sequence is accepted as the gold standard for detecting TAL injury. An increase in ADI beyond 3 mm observed on orthogonal CT imaging of the spine, which is rapid and more accessible in a trauma setting, provides indirect evidence of TAL failure. Dynamic imaging, showing an increase in ADI by more than 15% upon mild cervical flexion (~10 degree), may further increase sensitivity of CT toward detection of TAL injury.[17,28] CT may also show avulsion of osseous attachment of TAL that has a very favorable chance of healing with conservative management as compared with the disruption of ligamentous tissue.[3]

However, it should be noted that an atlantodental interval (ADI) less than 3mm does not necessarily mean that TAL is intact. Similar is the case for LD of less than 7 mm.[17,29] This is
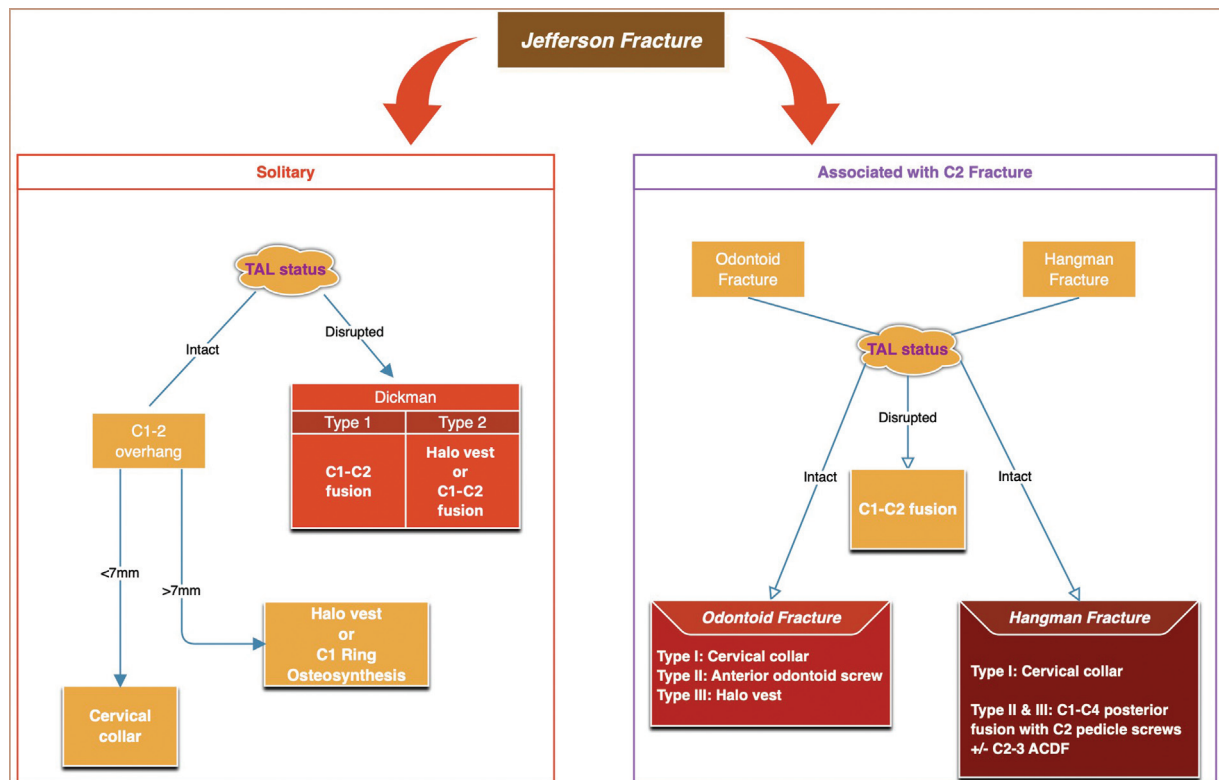
Fig. 6 Algorithm for the management of C1 to 2 fractures. TAL, transverse atlantal ligament.

because of ligamentotaxis and due to this phenomenon, the conventional radiology is sometimes not predictive of the original severity and extensiveness of injury. Here, the role of dynamic scans and direct visualization of TAL on MRI comes into play.

The management of atlas fractures is primarily determined by associated injuries to the TAL and the C2 vertebra. When coexistent with injuries to the axis vertebra, the treatment plan of atlas fracture is dictated by the C2 fracture.[4–6] In patients with an intact TAL, visualized through MRI, the overhang of the C1 LM provides vital clues to an existent mild ligamentous injury that might be missed by MRI. Consequently, in this group of patients, an overhang of more than 7 mm prompts an application of halo vest for immobilization, while in patients with lower value of the overhang, a hard cervical collar should suffice.[30]

In patients, where MRI shows a TAL disruption, it is important to characterize it as bony avulsion or other type of ligamentous injury through a high-resolution CT imaging. Patients with bony avulsion can heal with halo immobilization, while those with nonbony ligamentous failure would require surgical fixation.

A detailed algorithm has been proposed for the management of atlantoaxial fractures (►Fig. 6).

Conclusion

Jefferson fracture requires surgical intervention only infrequently. However, in cases where surgical fixation is needed, it is important to carefully anticipate the alterations in the anatomical relationships caused by the disruption of the C1 ring, so that surgical mishaps can be avoided. A CT-MRI correlation in establishing the TAL injury rather than predicting it using LD is quintessential for decision making and further management.

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