CLINICAL ARTICLE

Does C₁ Fracture Displacement Correlate with Transverse Ligament Integrity?

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Objective: The Rule of Spence states that displacement of the C₁ lateral masses by >6.9–8.1 mm suggests loss of transverse ligament integrity. The purpose of this study was to establish the thresholds of C₁ displacement on CT scans that correspond to transverse ligament disruption.

Methods: Over four years, consecutive patients with acute C₁ fractures with at least three fracture lines were analyzed. CT measurements and MRI were assessed by blinded observers for bony displacement in the axial (internal and external lateral mass separation), coronal and sagittal planes and transverse ligament integrity.

Results: Eighteen patients were studied. Mean CT bony measurements were as follows: internal border lateral mass separation (ILM) 23.3 ± 3.4 mm, external border lateral mass separation (ELM) 50.3 ± 4.3 mm, total C₁ lateral mass overhang over the C₂ superior process (LMO) 5.4 ± 1.3 mm. Twelve patients were identified as having intact transverse ligament and six had transverse ligament disruption. There was no difference in mean normalized ILM, ELM, or LMO between patients with or without transverse ligament integrity ($P > 0.05$).

Conclusion: There was no correlation between bony displacement and transverse ligament integrity. CT scans post-injury may not show the position of maximal displacement. If there is clinical concern about a possible transverse ligament injury, MRI should be performed.

Key words: C₁ fracture; computed tomography; Magnetic resonance imaging; Rule of Spence; Transverse ligament

Introduction

Fractures of the atlas comprise approximately 2% of all spinal injuries, 10% of all injuries to the cervical spine and 25% of all injuries to the atlanto-axial complex^{1–4}. In the 1920's, Jefferson reviewed 42 patients with atlas fractures and classified them into different patterns varying from isolated anterior ring fracture, isolated posterior ring fracture, lateral mass fracture, multiple ring fractures (unilateral or bilateral) and combinations thereof⁵. The classic Jefferson fracture involves a bilateral posterior arch fracture and a unilateral anterior arch fracture associated with displacement of the lateral masses⁵.

Levine and Edwards published a large series of atlas fractures; the most common was an isolated fracture of the posterior arch, followed by a burst fracture type (Jefferson fracture)^{6,7}. Whereas isolated arch fractures (anterior or posterior) are considered stable because there is no damage to the transverse ligament, a burst-fracture (Jefferson) type may cause instability of the atlanto-axial complex because of diastasis of the lateral masses⁷. Atlas fractures have been categorized as stable or unstable based on the integrity of the transverse ligament^{8–10}. To determine the stability of the atlanto-axial complex several methods have been used: plain

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X-rays, dynamic (flexion-extension) X-rays, CT scans and MRI¹¹.

Magnetic resonance imaging is the established gold-standard imaging modality for assessing transverse ligament integrity¹². However, many patients are unable to undergo MRI because of contraindications such as pacemakers, cochlear implants, claustrophobia, medical instability or retained metallic foreign bodies. Furthermore, patients with C₁ Jefferson fractures do not routinely undergo MRI at our institution; MRI is performed only when there is a suspicion of transverse ligament injury (TLI). There is a paucity of data in current published reports to guide clinicians as to which patients with Jefferson fractures need MRI to evaluate the possibility of transverse ligament injury. Additionally, in patients who are unable to undergo MRI, measures of bony displacement are often used to identify ligamentous injury.

Thin-section CT scans have become the screening modality of choice in many trauma centers because they improve visualization of bony structures and fracture patterns. To the authors' knowledge, there have been no published studies on the threshold measurements for TLI in patients with Jefferson fractures using modern imaging modalities (CT and MRI). The purpose of this study was to identify diagnostic criteria for transverse atlantal ligament (TAL) injury to improve early diagnosis and management of significant instability. The hypothesis of this study was that bony displacement of the C₁ lateral masses correlates with TLI.

Materials and Methods

Study Patients

This is a retrospective case series of patients with acute C₁ fractures. Following institutional board approval, a prospectively collected spinal cord injury center database was searched for consecutive C₁ fractures from 2006 to 2010.

The inclusion criteria for this study were as follows: acute C₁ fracture; burst-fracture (Jefferson) with at least three fracture lines; CT scans and MRI available; and at least 18 years old. All C₁ fractures were directly examined by the authors (LM

Fig. 1 CT scan—Axial view: internal lateral mass displacement measurement.

Fig. 2 CT scan—Axial view: external lateral mass displacement measurement (ELM).

and MS) to ensure they were acute injuries with at least three fracture lines, in accordance with the criteria for Jefferson fractures.

The exclusion criteria were as follows: inadequate imaging (X-rays, CT scans and/or MRI); non-acute fractures; pathologic fractures caused by infectious or inflammatory processes; metastatic lesions; children and associated anatomic variations (e.g., Klippel-Feil).

Fracture displacement was directly measured on CT scan using the clinically available PACS software (Phillips Isite) in the scout line mode to determine the orientation of the plane of measurement. All variables were measured three times by two fellowship-trained spine surgeons.

Several variables for measuring the bony displacement of the atlas lateral mass were used¹³, namely internal lateral mass border separation (ILM), external lateral mass border separation (ELM) and C₁ lateral mass overhang over the C₂ superior articular processes (LMO). Both axial and coronal views of CT scans were used to measure these variables.

Internal lateral mass border separation was defined as corresponding to the anatomic course of the TAL. The ILM was measured on an axial CT scan bisecting the C₁ lateral masses as the shortest distance from the medial aspect of one lateral mass to the contralateral lateral along a tangent line to the posterior odontoid (Fig. 1). The ELM was defined and measured from lateral lateral mass to lateral lateral mass along the same axis tangent as the posterior odontoid (Fig. 2).

To reproduce the lateral mass overhang commonly observed on open mouth radiographs, C₁ lateral mass overhang was defined. The LMO was measured on a coronal view bisecting the C₁ lateral masses from the lateral aspect of the C₁ lateral mass to the lateral aspect of the axis (C₂), similar to the Rule of Spence. The sum of the left and right side overhang was recorded (Fig. 3).

After the CT scans measures had been obtained, the MRIs were reviewed by two fellowship-trained orthopedic spine surgeons (LM, MS) blinded to the CT measurements for: TLI (rupture, edema), spinal cord injury (contusion; edema and/or hemorrhage) and spinal cord compression (Fig. 4).

Fig. 3 CT scan—Coronal view: total overhang measure; sum of the bilateral mass overhang.

Their findings were correlated with the findings of the attending neuroradiologist as stated on the MRI report. Determination of TAL integrity on MRI was performed as reported in a published report¹⁴. The transverse ligament was viewed initially on C₁ axial images bisecting the C₁ lateral masses to determine the continuity of a low signal intensity structure posterior to the odontoid inserting onto the medial aspect of both C₁ lateral masses. Then the transverse ligament was viewed on T₂ axial images to identify the presence of

fluid signal in the location where low signal intensity ligament should be present. Either anatomical disruption of the TAL on T₁ images or fluid signal in the TAL on T₂ images was considered to represent disruption of the transverse ligament.

Statistics were calculated using SPSS 18.0. Pearson correlation coefficients were calculated for parametric variables. Spearman rank order correlation coefficients were used to calculate the relationship between nonparametric variables such as measurement variables and ligament integrity. The independent samples *t*-tests was used to compare CT variables in patients with and without TLII.

Results

Relevant Patient Variables

Twenty-four consecutive patients were identified as having possible Jefferson type fractures in the overall study population. Six of them were excluded from the study because they did not meet the inclusion criteria. Three had non-acute fractures, one was younger than 18 years old and two did not have complete CT scans and MRI assessment. Thus, 18 patients (nine women and nine men) who met the inclusion criteria were included in this study. The mean age was 68.66 years. The most common mechanism of injury was a fall from a height. The most commonly associated injury was an odontoid fracture, which occurred in eight patients.

Bony Displacement Measures

The mean ILM was 23.3 ± 3.4 mm and the mean ELM 50.3 ± 4.3 mm. The total overhang (the sum of the left side and right side overhang measured on the midcoronal CT scan) had a mean value of 5.4 ± 1.3 mm (Table 1).

Fig. 4 MRI T₂ axial view (Red arrows depict low signal intensity) (a) Representative example of transverse ligament disruption from its bony insertion on the left C₁ lateral mass (arrow) (b) Representative example of transverse ligament disruption from the left side midsubstance (arrow).

Discussion

Our findings show that there is no significant relationship between injury to the transverse ligament complex and C₁ bony displacement on CT scan. Because the presence or absence of injury cannot be reliably ascertained based on bony displacement, we conclude that if there is clinical concern about the TLI, the transverse ligament should be directly imaged with MRI.

Recognition of TAL injury is important in prevention of late instability or atlas fracture nonunion. The transverse ligament is the major component of the cruciate ligamentous complex, which is responsible for atlanto-axial stability. Rupture or avulsion of this ligament results in atlanto-axial instability and is associated with a higher risk of neurologic injuries and disability. Using health-related quality of life questionnaires, Dvorak *et al.* showed that patients with residual atlanto-axial instability after atlas fracture have poorer outcomes than those who do not¹⁵.

In 1970, Spence *et al.* studied the axial load and lateral mass displacement required to disrupt the transverse ligament in 10 human cadaver specimens and concluded that if the sum of displacement of the lateral mass exceeds 6.9 mm after an atlas fracture, the transverse ligament is disrupted¹⁶. Clinicians have applied this finding, commonly referred to as the rule of Spence, to plain radiographic studies to determine whether the transverse ligament is ruptured. Heller *et al.* investigated the role of X-ray magnification in open-mouth (odontoid) views based on the rule of Spence and redefined this value to 8.1 mm¹⁷. Since the Heller study, the modified so-called "Rule of Spence" has commonly been used to assess the integrity of the transverse ligament after atlas fractures.

Dickman *et al.* attempted to validate the rule of Spence in a clinical series of 25 patients with TLI¹⁸. These authors diagnosed fracture displacement with open mouth radiographs and correlated displacement with ligamentous integrity on MRI, the gold standard clinical diagnostic modality for TAL injury. One of their findings was that if they applied the rule of Spence (7.0 mm criterion), they missed 61% of transverse ligament injuries. They were unable to identify threshold measurements for reliably identifying TAL injury. In contrast to the current study, the authors utilized open mouth radiographs, not CT scans. CT scans offers more precise resolution of bony displacement and are not susceptible to magnification error¹⁷. Furthermore, CT scan is the screening study of choice in many trauma centers.

In this study, we attempted to reproduce the lateral mass overhang previously measured on open mouth radiographs on

coronal CT scans. The mean overhang in our patients with Jefferson fractures was 5.4 ± 1.3 mm. This value is similar to that identified by Spence in his original work¹³. However, there was no relationship with, or threshold of, overhang that reliably identified TAL injury. We then attempted to create a new measurement of TAL integrity by measuring the theoretical ligament length along its anatomical course posterior to the odontoid. Such a measurement is likely impossible in a radiographic or cadaveric study. We defined the internal lateral border separation as corresponding to the anatomic course of the TAL from the insertion of the TAL on one lateral mass to the contralateral lateral mass along a tangent line to the posterior cortex of the dens.

We found no statistically significant correlation between transverse ligament disruption seen on MRI and bony displacement as measured by ILM, ELM or total overhang. These results are consistent with those of another biomechanical study published by Beckner *et al.* that showed no difference in displacement of atlas fractures between specimens in which the transverse ligament was intact and in those without a transverse ligament¹⁹.

The strengths of this study include the large, prospectively collected, comprehensive database and the homogenous group of patients with Jefferson fractures. Earlier studies may have included occipitocervical dislocations or other confounding injuries. The limitations of this study include the retrospective nature of the analysis and the small number of patients with true Jefferson fractures. There is a possibility of type II error that our study population may have been underpowered to detect. We attribute the small number of patients to our rigid inclusion criteria (each patient was reviewed for at least three fracture lines prior to inclusion) and the relative rarity of this injury. However, we would argue that to be validated as a diagnostic criterion, the effect size relationship between CT displacement and MRI should be robust. Further studies with larger sample sizes, possibly from multiple institutions, may be necessary to resolve this question definitively.

Based on our results, we propose that CT scans are appropriate for delineating bony fragments associated with atlas fractures, but even with accurate measurements of bony displacement variables, the integrity of the transverse ligament cannot be assured. Where there is any concern about transverse ligament integrity, a MRI should be ordered to directly image the structure of interest. The degree of bony displacement on imaging does not necessarily reflect the degree of displacement at the time of impact.

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