

Radiologic criteria to predict injury of the transverse atlantal ligament in unilateral sagittal split fractures of the C1 lateral mass

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Abstract

Unilateral sagittal split fracture (USSF) of the C1 lateral mass (LM) has been recently recognized as a rare variant of C1 atlas fracture. To date, there has been no study to investigate whether radiologic criteria can be applied to determine the presence or absence of transverse atlantal ligament (TAL) injury in USSF of the C1 LM.

Twenty six consecutive cases of USSF of the C1 LM were included in this study. According to Dickman classification, 16 cases were TAL injury, and 10 cases were TAL intact. Radiologic parameters were measured and compared between the 2 groups.

Total LM displacement (LMD) of the 2 sides (5.9 ± 2.0 mm vs 1.2 ± 2.0 mm), unilateral LMD of the fracture side (4.3 ± 1.2 mm vs 1.0 ± 1.1 mm), atlanto-dental interval (ADI) (2.0 ± 0.9 mm vs 1.5 ± 0.4 mm), and fracture gap (6.9 ± 2.7 mm vs 2.1 ± 1.1 mm) were statistically higher in the TAL injury group than the TAL intact group. However, basion-dental interval, clivus canal angle, and atlanto-occipital joint axis angle were not different between the 2 groups. Total LMD and unilateral LMD positively correlated with ADI and fracture gap. The incidence of fracture gap larger than 7 mm was statistically higher in the TAL injury group than the TAL intact group (81% vs 30%).

In conclusion, total LMD > 5.9 mm or unilateral LMD > 4.3 mm suggests the presence of TAL injury in USSF of the C1 LM. The possibility of diagnostic error for TAL injury can be further reduced in USSF of the C1 LM by considering the fracture gap larger than 7 mm.

Abbreviations: ADI = atlanto-dental interval, AOJAA = atlanto-occipital joint axis angle, BDI = basion-dental interval, CCA = clivus canal angle, CT = computerized tomography, LM = lateral mass, LMD = lateral mass displacement, MRI = magnetic resonance imaging, TAL = transverse atlantal ligament, USSF = unilateral sagittal split fracture.

Keywords: C1 lateral mass, radiologic criteria, transverse atlantal ligament, unilateral sagittal split fracture

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H-JP and D-GC equally contributed to this study as the co-first author.

This retrospective study was approved by the Institutional Review Board of the Uijeongbu St. Mary's Hospital (e-IRB UC19RES1006) and informed written consent was obtained from the patient for publication of this study and accompanying images.

The authors have no conflicts of interests to disclose.

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1. Introduction

Unilateral sagittal split fracture (USSF) of the C1 lateral mass (LM) has been recently recognized as a rare variant of C1 atlas fracture.^[1-4] The most important factor in determining the stability of C1 atlas fracture is the presence or absence of transverse atlantal ligament (TAL) injury. If there is no TAL injury, the fracture is regarded as stable, and conservative treatment is performed. However, if a TAL injury is identified, the fracture is regarded as unstable, and surgical treatment is performed. There are several radiologic criteria to diagnose TAL injury in C1 atlas fracture, especially Jefferson fracture. The most representative method is to measure lateral mass displacement (LMD).^[5,6] If the total LMD exceeds 6.9 mm, there is high likelihood of TAL injury in a Jefferson fracture; if LMD is less than 5.7 mm, TAL injury is unlikely.

Due to the rarity of USSF of the C1 LM, previously published studies are case reports or small case series. Definitive diagnostic criteria to determine the stability of USSF of the C1 LM have yet to be established.^[1-4] Jefferson fracture and USSF of the C1 LM are in the same category as C1 fracture. However, the 2 fracture entities are different in several aspects, including injury mechanism and pattern and severity of fracture. It has been reported that conservative treatment of USSF of the C1 LM causes late deformity of the occipitocervical junction, which can require occipitocervical reconstructive fusion surgery.^[3,4] Therefore, it is necessary to verify whether the LMD criteria used to diagnose TAL injury in Jefferson fractures can be applied to

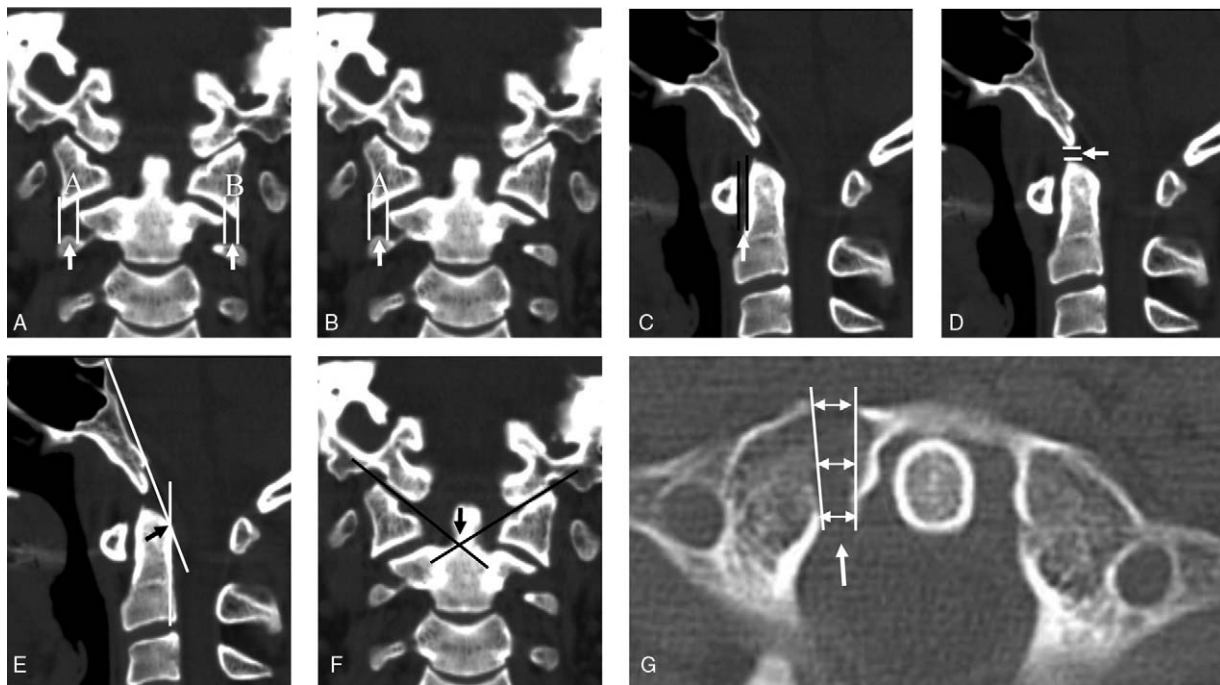


Figure 1. Measurements of radiological parameters. Total lateral mass displacement (1a), fracture side lateral mass displacement (1b), atlanto-dental interval (1c), basion-dental interval (1d), clivus canal angle (1e), atlanto-occipital joint axis angle (1f), and fracture gap (1g). Measurements of radiological parameters were performed based on methods described in previously published papers.^[9–11] Fracture gap was measured at points the proximal, middle, and distal of the fracture.

USSF of the C1 LM or whether the criteria need to be revised for USSF of the C1 LM. The purpose of the current study was to investigate the radiologic criteria utilized to determine the presence of TAL injury in USSF of the C1 LM, an unstable fracture requiring surgical treatment.

2. Materials and methods

Twenty six consecutive cases of USSF of the C1 LM were included from 5 trauma centers of tertiary university hospitals for retrospective analysis. Fractures associated with other high cervical spine regions, such as C2 and occiput, were excluded from the study. The mean age was 52 years (range, 32–69 years). Sixteen participants were male and 10 were female. At the time of initial presentation, fracture pattern of the C1 LM, and presence and type of TAL injury were evaluated by plain radiographs, magnetic resonance imaging (MRI), and computerized tomography (CT).

Two radiologists evaluated and determined the presence and type of TAL injury on MRI and CT using Dickman classification, and the patients were divided into 2 groups: TAL injury and TAL intact.^[7,8] If the assessments of the 2 radiologists were not identical, a third radiologist evaluated the films, and his assessment was used as the final result. Three spine surgeons measured the radiologic parameters on a 2-dimensional sagittal and coronal reconstructed CT scan and MRI that were obtained upon initial presentation. Measured radiologic parameters were as follows: total LM displacement (LMD) of the 2 sides, unilateral LMD of the fracture side, atlanto-dental interval (ADI), basion-dental interval (BDI), clivus canal angle (CCA), atlanto-occipital joint axis angle (AOJAA), and fracture gap (Fig. 1).

Measurements were based on methods described in previously published papers.^[9–11] The LMD was defined as the distance between the lateral margin of the C2 dens body and that of the C1 LM. The distance between the anterior arch of the atlas and the anterior cortex of the dens was defined as the ADI. The distance between the basion and the tip of the dens was defined as the BDI. The CCA is the angle formed by Wackenheim line and a line constructed along the posterior margin of the dens and axis body. The AOJAA is formed at the intersection of tangents drawn parallel to the atlanto-occipital joints. Three measurements were performed for each parameter, and the average was used as the final result. Fracture gap was measured at points proximal, middle, and distal of USSF, and the average of 3 measurements was used as the final result.

Radiologic parameters were compared between the TAL injury group and the TAL intact group. For statistical analyses, independent sample *t*-test and Pearson correlation test were used. A *P* value less than .05 was considered statistically significant. Sensitivity and specificity of MRI to diagnose TAL injury in USSF of C1 LM were calculated with the two-by-two table method (Table 2). This multicenter retrospective study was approved by the Institutional Review Board of the corresponding author university hospital and informed written consent was obtained from the patient for publication of this study and accompanying images.

3. Results

Sixteen cases were TAL injury, and 10 were TAL intact. Among the 16 cases of TAL injury, 9 were type I ligamentous injury, and 7 were type II bony avulsion injury. Demographic data are

Table 1
Comparison of demographic data of sagittal split fractures of C1 lateral mass with TAL injury vs TAL intact at initial presentation.

	TAL injury (N=16)	TAL intact (N=10)
Age (years)	52.1 ± 11.1	51.7 ± 9.2
Gender		
Male	11 (69%)	5 (50%)
Female	5 (31%)	5 (50%)
Injury mechanism, Number (%)		
Fall down	11 (69%)	7 (70%)
Traffic accident	4 (25%)	2 (20%)
Diving	1 (6%)	1 (10%)
Neurologic status		
ASIA impairment scale	E: 16 (100%)	E: 10 (100%)
Frankel grade	E: 16 (100%)	E: 10 (100%)

summarized in Table 1. Age, sex, injury mechanism, and neurologic status at initial presentation were not statistically different between the TAL injury and TAL intact groups. All cases were conservatively treated with rigid brace or halovest for 3 months.

The sensitivity and specificity of MRI to diagnose the TAL injury in USSF of C1 LM was 81.3% and 80%, respectively. The results of comparisons of the radiologic parameters between the TAL intact and TAL injury groups are summarized in Table 3. Total LMD of the 2 sides (5.9 ± 2.0 mm vs 1.2 ± 2.0 mm, $P < .001$), unilateral LMD of the fracture side (4.3 ± 1.2 mm vs 1.0 ± 1.1 mm, $P < .001$), ADI (2.0 ± 0.9 mm vs 1.5 ± 0.4 mm, $P < .05$), and fracture gap (6.9 ± 2.7 mm vs 2.1 ± 1.1 mm, $P < .001$) were significantly higher in the TAL injury group than the TAL intact group (Figs. 2 and 3). However, BDI, CCA, and AOJAA were not statistically different between the 2 groups (4.4 ± 1.4 mm vs 4.2 ± 1.4 mm, $P = .751$) ($155.6 \pm 7.1^\circ$ vs $154.9 \pm 9.4^\circ$, $P = .824$) ($107.8 \pm 8.7^\circ$ vs $105.9 \pm 14.0^\circ$, $P = .676$). Incidence of a fracture gap greater than 7 mm was statistically higher in TAL injury than TAL intact (81% vs 30%, $P < .001$) (Table 4).

Total LMD of the 2 sides significantly correlated with unilateral LMD of the fracture side ($CC = 0.937$, $P < .001$), ADI ($CC = 0.499$, $P < .01$), and fracture gap ($CC = 0.617$, $P < .01$) (Table 5). In addition, unilateral LMD of the fracture side significantly correlated with total LMD of the 2 sides ($CC = 0.937$, $P < .001$), ADI ($CC = 0.449$, $P < .05$), and fracture gap ($CC = 0.658$, $P < .001$) (Table 6).

4. Discussion

To select the appropriate treatment strategy, physicians must determine the presence or absence of TAL injury in a patient with a C1 burst fracture, first described as a Jefferson fracture in 1927.^[11-14] If there is no TAL injury, the fracture is regarded as

Table 2
Basic setup for 2 × 2 table to calculate diagnostic values*.

MRI	TAL injury	
	Positive	Negative
Positive	True positive (TP)	False positive (FP)
Negative	False negative (FN)	True negative (TN)

* Diagnostic values were calculated with the following equations: sensitivity = TP / (TP + FN); specificity = TN / (FP + TN). TAL = Transverse atlantal ligament.

Table 3
Comparison of radiological data of sagittal split fractures of C1 lateral mass with TAL injury versus TAL intact at initial presentation.

	TAL injury (N=16)	TAL intact (N=10)	P value
Total LMD (mm)	5.9 ± 2.0	1.2 ± 2.0	$P < .001$
Unilateral LMD (mm)	4.3 ± 1.2	1.0 ± 1.1	$P < .001$
ADI (mm)	2.0 ± 0.9	1.5 ± 0.4	$P < .05$
BDI (mm)	4.4 ± 1.8	4.2 ± 1.4	$P = .751$
CCA (degree)	155.6 ± 7.1	154.9 ± 9.4	$P = .824$
AOJAA (degree)	107.8 ± 8.7	105.9 ± 14.0	$P = .824$
Fx gap (mm)	6.9 ± 2.7	2.1 ± 1.1	$P < .001$

stable, and conservative treatment is elected. But, a patient with a C1 burst fracture and concomitant TAL injury must be regarded as having an unstable fracture, surgical treatment is performed. There are several radiologic criteria used to diagnose TAL injury in C1 atlas fracture, especially a Jefferson fracture. The most reliable method for detecting TAL injury is the rule of Spence: if total LMD of the 2 sides exceeds 6.9 mm, there is a high likelihood of TAL injury in Jefferson fracture; if LMD is less than 5.7 mm, a TAL injury is unlikely.

However, some studies have argued that there is controversy in the relationship between LMD and TAL injury. According to Dickman et al, LMD greater than 7 mm misses 61% of TAL injuries.^[7,8] Perez-Orribo et al claimed that the rule of Spence is not sensitive enough for TAL injury.^[15] Therefore, the use of MRI is recommended for detecting TAL injury. However, MRI may be unavailable or of insufficient quality in some hospitals. In addition, considering the anatomical characteristics of the TAL, it may not be easy to assess MRI axial images by accurately matching axial cross-sections and TAL. Despite the controversy regarding the diagnostic accuracy of LMD and ADI, physicians must measure both to diagnose TAL injury in patients with C1 atlas fracture to determine the best treatment strategy. In addition, USSF of the C1 LM is rare, and the definitive diagnostic criteria to determine its stability are yet to be established.

In the current study, we diagnosed TAL injury in 26 cases of USSM of the C1 LM and classified the patients into 2 groups: TAL intact and TAL injury. Next, we measured and compared the radiological parameters between the 2 groups. Our results demonstrated that total LMD (5.9 mm vs 1.2 mm) and unilateral LMD (4.3 mm vs 1.0 mm) were statistically higher in TAL injury than TAL intact. Total LMD and unilateral LMD positively correlated with ADI and fracture gap. Differing from the rule of Spence (total LMD > 6.9 mm) indicates TAL injury in patients with C1 burst fracture, total LMD > 5.9 mm or unilateral LMD > 4.3 mm should be the radiological criteria used to predict the presence of TAL injury in USSF of the C1 LM, an unstable fracture. Jefferson fracture and USSF of the C1 LM are in the same category of C1 fracture but differ in several aspects, including injury mechanism and pattern and severity of fractures. Based on the current results, we suggest that the rule of Spence needs to be revised for USSF of the C1 LM.

Another method used to assess TAL injuries is measurement of the ADI. If ADI exceeds 3 mm, there is high likelihood of TAL injury. Similar to the LMD/TAL injury relationship, there is also controversy in the relationship between ADI and TAL injury. Oda et al reported that ADI was the best diagnostic tool for TAL

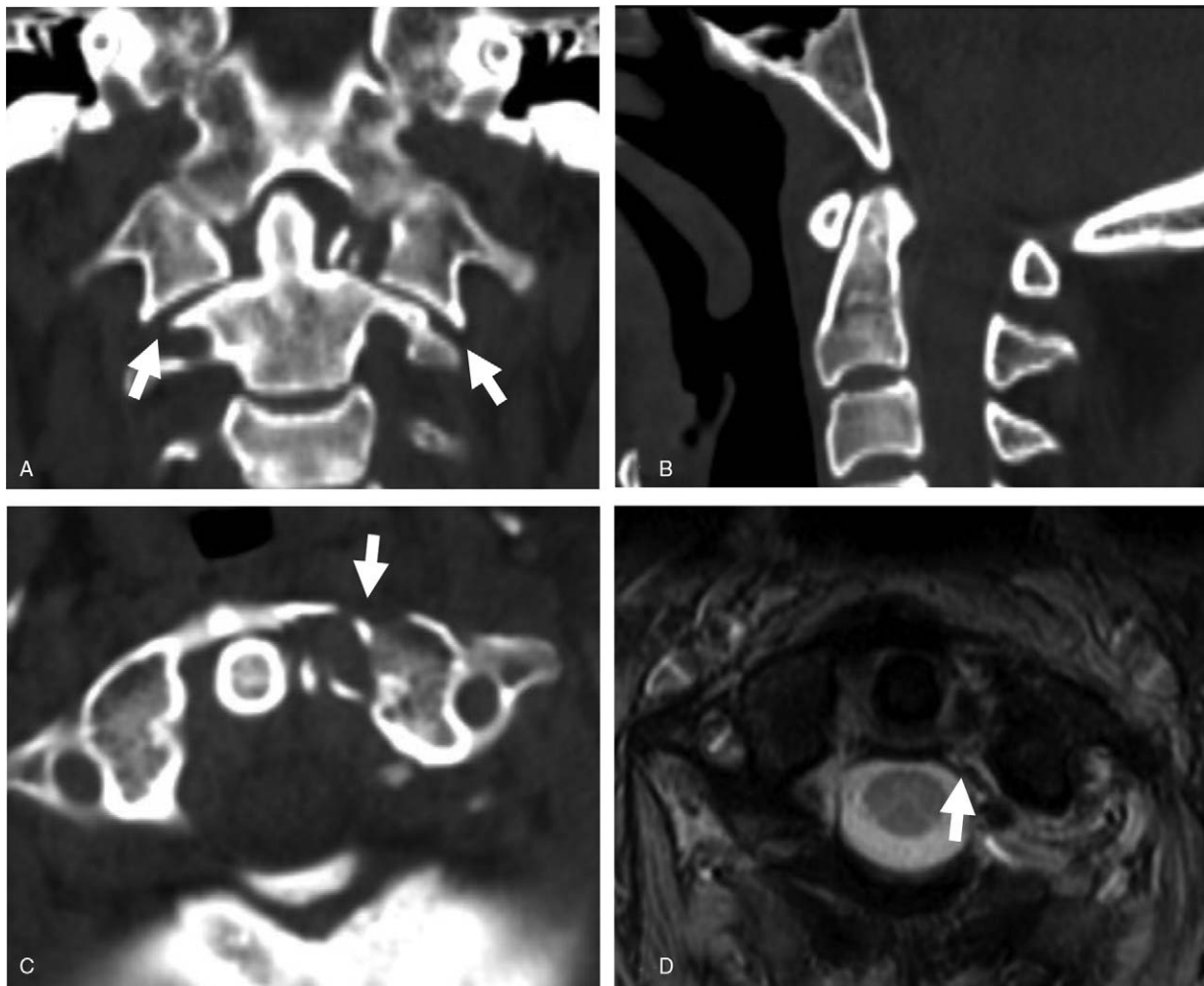


Figure 2. Unilateral sagittal split fracture with transverse atlantal ligament injury. 2-dimensional coronal (2a) and sagittal (2b) CT scans showing increased total and unilateral lateral mass displacements (white arrows). Axial CT (2c) and MRI (2d) showing increased fracture gap of unilateral sagittal split fracture and injury of transverse atlantal ligament (white arrows).

injury.^[16] However, Perez-Orribo et al claimed that ADI is not sensitive for TAL injury.^[15] In the current study, ADI was statistically higher in TAL injury than TAL intact (2.0 mm vs 1.5 mm), but the actual ADI was within the normal range. This inconsistency may be explained by the fact that all radiologic examinations were performed immediately after injury. TAL injuries were not sufficient to cause a significant increase in ADI in USSM of the C1 LM.

An important result to be noted in this study is the increased fracture gap of USSM of the C1 LM in patients with TAL injury. Fracture gap of USSF of the C1 LM was significantly higher in the TAL injury group than the TAL intact group (6.9 mm vs 2.1 mm). In addition, the incidence of fracture gap greater than 7 mm was statistically higher in the TAL injury group than the TAL intact group (81% vs 30%). Therefore, if the size of the fracture gap is considered in evaluation and diagnosis, the possibility of diagnostic error for TAL injury can be further reduced in patients with USSF of the C1 LM. Measuring the fracture gap to assess the TAL injury in patients with USSM of the C1 LM is the first significant result of our study.

In the current study, we did not describe clinical and radiological outcomes of conservative treatment for USSF of C1 LM with TAL injury and TAL intact groups. So, detailed clinical and radiological outcomes will be published separately published in other manuscript.^[3,4] In brief, for TAL intact group, total LMD, unilateral LMD, ADI, BDI, CCA, AOJAA were well maintained compared to initial presentation. However, for TAL injury group, all radiological parameters were worsened. Neck visual analog scale significantly decreased and patient's satisfaction was higher in TAL intact group compared to TAL injury group. Based on our findings, we recommend early surgical treatment, including C1 motion preserving screw fixation or C1-C2 segmental fixation, for patients with radiologic findings that suggest USSF of the C1 LM with concomitant TAL injury to avoid or minimize loss of motion by occipitocervical reconstructive fusion surgery.

The limitation of this study is retrospective study design. Since USSF of the C1 LM is rare, the large number of USSF of the C1 LM cases analyzed in our study can reduce the limitation of our study.

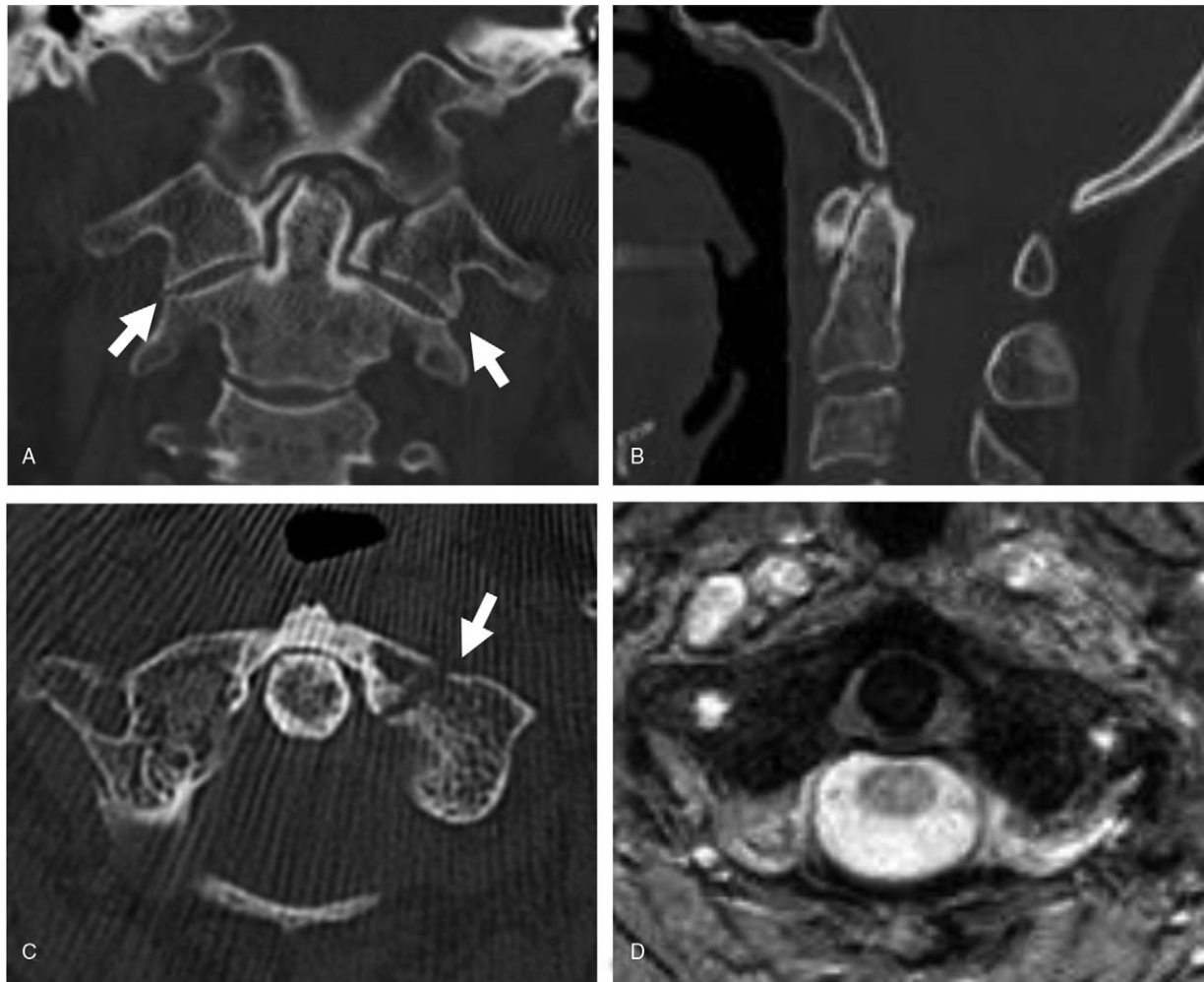


Figure 3. Unilateral sagittal split fracture with transverse atlantal ligament intact. 2-dimensional coronal (3a) and sagittal (3b) CT scans showing not increased total and unilateral lateral mass displacements (white arrows). Axial CT (3c) and MRI (3d) showing slightly increased fracture gap of unilateral sagittal split fracture (white arrow) and intact transverse atlantal ligament.

Table 4
Frequency analysis in sagittal split fracture of C1 lateral mass with TAL injury vs TAL intact at initial presentation.

	TAL Injury (N=16)	TAL Intact (N=10)	P value
Fx gap			<i>P</i> < .001
≥7 mm	13 (81%)	3 (30%)	
<7 mm	3 (19%)	7 (70%)	

Fx=Fracture, TAL=Transverse atlantal ligament, *P* value was calculated by Chi-Squared test.

Table 5
Correlation analysis of radiologic parameters in sagittal split fracture of C1 lateral mass at initial presentation.

	Unilateral LMD (mm)	ADI (mm)	Fx gap (mm)
Total LMD (mm)	CC=0.937	CC=0.499	CC=0.617
<i>P</i> value	<i>P</i> < .001	<i>P</i> < .01	<i>P</i> < .01

P value was calculated by Pearson test.
 ADI=atlanto-dental interval, CC=Correlation coefficient, Fx=Fracture, LMD=Lateral mass displacement.

In conclusion, our study suggests that total LMD > 5.9 mm or unilateral LMD > 4.3 mm is the preferred radiologic criterion to detect TAL injury in USSF of the C1 LM. The possibility of diagnostic error for TAL injury can be further reduced in USSF of the C1 LM by considering the fracture gap, and patients with a fracture gap greater than 7mm are more likely to have TAL injury.

Table 6
Correlation analysis of radiologic parameters in sagittal split fracture of C1 lateral mass at initial presentation.

	Total LMD (mm)	ADI (mm)	Fx gap (mm)
Unilateral LMD (mm)	CC=0.937	CC=0.449	CC=0.658
<i>P</i> value	<i>P</i> < .001	<i>P</i> < .05	<i>P</i> < .001

P value was calculated by Pearson test.
 ADI=Atlanto-dental interval, CC=Correlation coefficient, Fx=Fracture, LMD=Lateral mass displacement.

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