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The relationship between radiologic parameters and transverse atlantal ligament injury obtained from MRI scans in patients with an isolated atlas burst fracture

A retrospective observational study

Jongpil Eun, MD, PhD, Youngmin Oh, MD, PhD*

Abstract

The treatment of an atlas burst fracture depends on whether transverse atlantal ligament (TAL) injury is present. We compared the radiologic parameters associated with the presence of a TAL injury as detected using magnetic resonance imaging (MRI), and verified whether the lateral mass displacement (LMD) criteria currently used to diagnose TAL injuries in atlas burst fractures are reliable or need revision.

Thirty patients who presented with isolated atlas burst fractures were included in this retrospective observational study. We measured radiologic parameters, including LMD, atlanto-dental interval, basion-dens interval, internal lateral mass displacement, and external lateral mass displacement, in each patient at the time of initial presentation. The presence of TAL injury was evaluated using MRI. We compared the radiologic parameters and characteristics of patients who presented with TAL injury. We also determined the sensitivity and specificity of an LMD test to accurately diagnose TAL injury based on MRI. Finally, we compared the radiologic parameters according to the presence of surgical treatment and patient union status.

Twenty patients presented with an intact TAL, while 10 patients had a TAL injury on MRI. LMD was significantly higher in patients with TAL injury (9.61 vs 3.73 mm, $P<.001$). In multivariable logistic regression analysis, LMD was also significantly higher in patients with TAL injury. The sensitivity and specificity of LMD for diagnosing TAL injury based on MRI in patients with isolated C1 fractures were 90% and 100%, respectively. The incidence of an LMD greater than 8.1 mm was statistically higher in patients than in those without TAL injury (90% vs 0%, $P<.001$).

Nine patients underwent surgery for isolated atlas burst fractures, and 21 did not. LMD (9.56 vs 4.03 mm, $P<.001$) and fracture gap (7.96 vs 4.01 mm, $P<.001$) were significantly higher in patients who underwent surgery.

Among the various radiologic parameters, LMD closely correlated with the presence of TAL injury, as patients with an LMD greater than 8.1 mm were more likely to have a TAL injury in the case of atlas burst fractures. LMD is a good method for predicting the presence of TAL injury if MRI is not available.

Abbreviations: ADI = atlanto-dental interval, BDI = basion-dens interval, CC = correlation coefficient, CT = computed tomography, ELM = external lateral mass displacement, ILM = internal lateral mass displacement, LMD = lateral mass displacement, MRI = magnetic resonance imaging, MVA = motor vehicle accident, OCF = occipito-cervical fusion, TAL = transverse atlantal ligament.

Keywords: atlas fracture, C1 osteosynthesis, C1 surgery, C1/2 instability, cervical trauma, lateral mass displacement, magnetic resonance imaging, transverse atlantal ligament

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All data generated or analyzed during this study are included in this published article [and its supplementary information files].

Department of Neurosurgery, Biomedical Research Institute, Jeonbuk National University Medical School and Hospital, Jeonju, Korea.

** Correspondence: Youngmin Oh, Department of Neurosurgery, Jeonbuk National University Medical School and Hospital, Geonjiro 20, Deokjingu, Jeonju 54907, South Korea (e-mail: timoh@jbnu.ac.kr).*

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1. Introduction

C1 vertebral fractures account for approximately 3% to 13% of cervical spine fractures and 1.32% of all spinal injuries.[1,2] Since Jefferson seminal work reviewed 42 patients with atlas fractures and classified them into different groups, several additional classification systems have been introduced.[3,4] Gehweiler et al divided atlas fractures into 5 groups.[5] Atlas fractures can also be categorized as stable or unstable based on the integrity of the transverse atlantal ligament (TAL).[6,7] The treatment applied to C1 vertebral fractures depends on whether a TAL injury is present. In the absence of a TAL injury, the fracture is regarded as stable, and conservative treatment consisting of a cervical collar and Halovest application is recommended. However, if a TAL injury is present, the fracture is regarded as unstable and surgery is performed.[8–10] According to the "Rule of Spence," instability is assumed if the C1 overhang exceeds 6.9 mm on an open mouth anterior–posterior view X-ray, although it has been proposed by Heller et al that this number be adjusted to 8.1 mm to account for radiographic magnification factors.[11] However, recent studies have shown that there is little correlation between bony displacement visible through computed tomography (CT) scans and TAL integrity, casting doubt on the utility of the "Rule of Spence" for assessing TAL integrity.[1,6,12] Instead, Kakarla et al proposed replacing other imaging modalities with magnetic resonance imaging (MRI).[13] It is thus necessary, at this juncture, to verify whether the lateral mass displacement (LMD) criteria currently used to diagnosis a TAL injury in C1 fractures is reliable or whether the criteria need to be revised. Unfortunately, there is a paucity of published data related to the detection of TAL injuries using MRI. Because we routinely evaluate the integrity of the transverse ligament in patients with an atlas burst fracture using MRI in our department, we were able to compare the radiologic parameters of those patients with an atlas burst fracture with a TAL injury and those with an atlas burst fracture without a TAL injury. This is the first study to determine the efficacy of diagnosing TAL injuries using MRI in patients with isolated atlas burst fractures. In this study, we aimed to compare the radiologic parameters associated with the presence of a TAL injury, as detected by MRI, and to verify whether the LMD criteria currently used to diagnose TAL injuries in atlas burst fractures is reliable or needs revision. We additionally present an overview of 30 patients who were treated for traumatic isolated atlas burst fractures and discuss their outcomes.

2. Materials and methods

We retrospectively reviewed the medical records of our hospital between 2014 and 2019. We reviewed to find out the patients with atlas burst fractures. Patients with any other concurrent cervical or occipital fractures were excluded. Only patients who received a minimum of 6 months of follow-up were included in this study. A total of 30 patients who presented with isolated atlas burst fractures were ultimately included in this study, 23 of whom were male and seven of whom were female.

Information concerning the age, sex, mechanism of injury, C1 fracture type, management method, and the presence of instability 6 months after fracture were obtained (Table 1). The mechanism of injury was classified as either falling or motor vehicle accident (MVA). We measured the radiologic parameters, including LMD, atlantodental interval (ADI), basion-dens interval (BDI), internal lateral mass displacement (ILM), and external lateral mass displacement (ELM), in each patient at the time of initial presentation (Figure 1). This measurement was performed using methods described in previously published papers,[1] and 2 spine surgeons measured radiologic parameters on a sagittal and coronal reconstructed CT scan. The presence of a TAL injury was evaluated using MRI, and either anatomical disruption of the TAL on T1 images or fluid signal in the TAL on T2 images was regarded as representing disruption of the transverse ligament (Figure 2).[6] Atlas fractures were classified by type using the Gehweiler classification system: Type 1, isolated fracture of the anterior ring of the atlas; Type 2, isolated fracture of the posterior arch of the atlas; Type 3, combined fractures of the anterior and posterior arch of the atlas; Type 4, isolated fracture of the lateral mass; and Type 5, fracture of the transverse process. A presenting fracture was classified into 1 or more of these categories, depending on the radiologic findings. To reduce bias, we included patients with isolated C1 burst fractures of Type 3 or Type 4 only.

Table 1

Characteristics of the patients with isolated atlas burst fracture.

Characteristic		Value (n=30)
Number of patients		30
Age (yrs)		52.2±17.0
Sex	Male	23 (76.7%)
	Female	7 (23.3%)
Mechanism of injury	MVA	17 (56.7%)
	Fall down	13 (43.3%)
Fracture type (by Gehweiler)	Type 3	20 (66.7%)
	Type 4	10 (33.3%)
Management	Rigid cervical collar	2 (6.7%)
	Halo vest	19 (63.3%)
	Surgery	9 (30%)
Non-union (6 mo after fracture)		17 (56.7%)
Instability (6 mo after fracture)		0 (0%)

MVA=motor vehicle accident.

We compared the radiologic parameters and characteristics of patients who presented with TAL injuries. We also determined the sensitivity and specificity of an LMD test that would accurately diagnose a TAL injury based on MRI in patients with an isolated C1 burst fracture. Finally, we compared the radiologic parameters according to the presence of surgical treatment and the union status of the patient.

This retrospective observational study was approved by the Institutional Review Board of the Jeonbuk National University Hospital (No. 2021-09-022), and informed written consent was obtained from each patient for participation in this study.

Statistical analyses were performed using SPSS software (version 26.0). The independent samples t test was used to compare parametric data. Nonparametric data were compared using the chi-squared test. Regression analysis was performed using stepwise logistic regression, with an inclusion threshold for the multivariable model of $P<.10$ for candidate variables on single-variable logistic regression. Statistical significance was set at $P<.05$.

3. Results

3.1. Patient characteristics

Among the 30 patients who met the inclusion criteria, 7 (23.3%) were female and 23 (76.7%) were male. The average age of the patients was 52.2±17.0 years. Demographic data are summarized

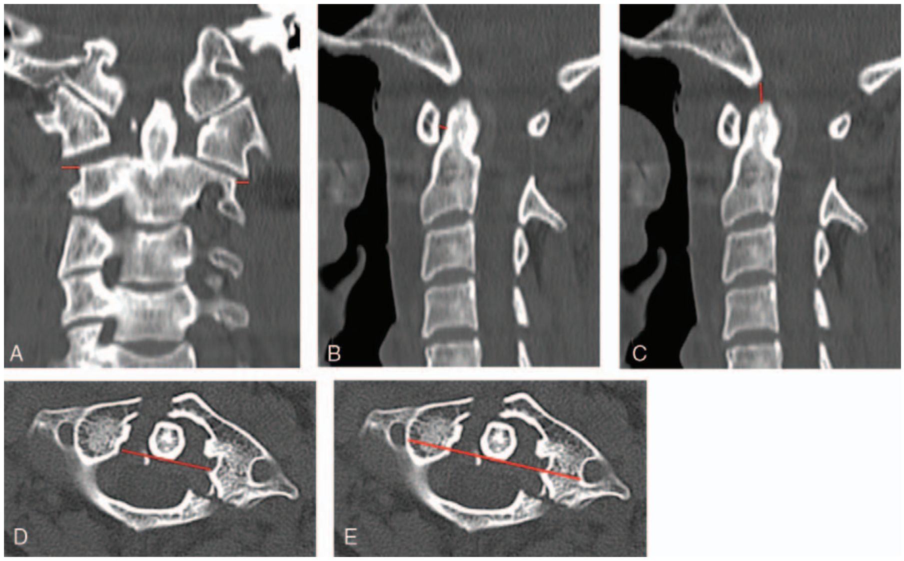

Figure 1. Measurement of radiologic parameters. (A) LMD, (B) ADI, (C) BDI, (D) ILM, and (E) ELM. ADI = atlanto-dental interval, BDI = basion-dens interval, ELM = external lateral mass displacement, ILM = internal lateral mass displacement, LMD = lateral mass displacement.

in Table 1. The most common mechanism of injury was MVA (17 patients, 56.7%) followed by trip-and-fall (13 patients; 43.3%). Nine patients underwent occipito-cervical fusion (OCF), C1/C2 fusion, or C1 osteosynthesis. Other patients were treated with a halo-vest (18 patients) or a rigid cervical collar (3 patients). Twenty patients had Type 3 fractures (66.7%), and 10 patients had Type 4 fractures (33.3%). Nonunion was noted on CT scans in 17 patients (56.7%). While over half of the patients failed to achieve union, no patient showed instability on the flexion-extension radiographs (at least 6 months post-treatment) (Table 1).

3.2. Differences in radiologic parameters according to TAL injury

Twenty patients presented with an intact TAL, while 10 patients had a TAL injury on MRI. No significant differences were seen in age (53.8 vs 49.1 years, $P = .485$), ADI (1.29 vs 1.84 mm, $P = .069$), or BDI (3.79 vs 3.19 mm, $P = .292$) between each set of patients. As expected, LMD was significantly higher in patients with TAL injury (9.61 vs 3.73 mm, $P < .001$). ILM and ELM were also higher in patients with TAL injury. Interestingly, the fracture gap was significantly higher in patients with TAL injury (8.12 mm) than in patients without TAL injury (3.74 mm, $P < .001$) (Table 2). However, when examined using multivariable logistic regression, only LMD was significantly higher in patients with TAL injury, while other parameters did not significantly differ (Table 3).

In the correlation analysis of radiologic parameters, LMD significantly correlated with ILM (correlation coefficient [CC] = 0.661, $P < .001$), ELM (CC = 0.705, $P < .001$), and fracture gap (CC = 0.840, $P < .001$) (Table 4).

The sensitivity and specificity of LMD for diagnosing TAL injury based on MRI in patients with isolated C1 fractures were 90% and 100%, respectively (Table 5). The incidence of an LMD greater than 8.1 mm was significantly higher in TAL-injury than in TAL-intact patients (90% vs 0%, $P < .001$) (Table 5).

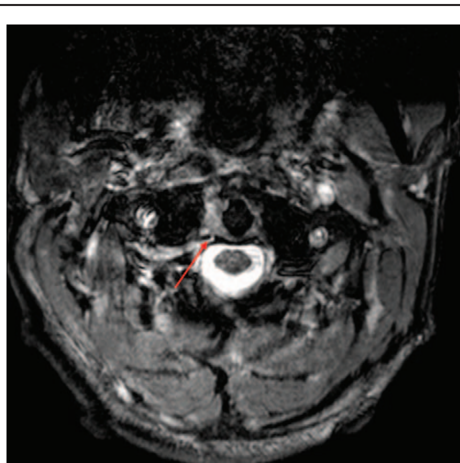

Figure 2. MRI T2 axial image. Representative example of TAL disruption from its bony insertion in the right C1 lateral mass (Arrow). MRI = magnetic resonance image, TAL = transverse atlantal ligament.

Table 2

Differences between the patients with TAL injury and the patients without TAL injury.

	Transverse atlantal ligament injury		
	No (n = 20)	Yes (n = 10)	*P* value
Age (yrs)	53.80 ± 17.84	49.10 ± 15.55	.485
ADI (mm)	1.29 ± 0.63	1.84 ± 0.95	.069
LMD (mm)	3.73 ± 2.36	9.61 ± 2.47	<.001*
BDI (mm)	3.79 ± 1.32	3.19 ± 1.67	.292
ILM (mm)	21.73 ± 3.74	26.86 ± 3.65	.001*
ELM (mm)	48.09 ± 3.83	53.09 ± 3.64	.002*
Fracture gap (mm)	3.74 ± 2.31	8.12 ± 1.90	<.001*

ADI = atlanto-dental interval, BDI = basion-dens interval, ELM = external lateral mass displacement, ILM = internal lateral mass displacement, LMD = lateral mass displacement, TAL = transverse atlantal ligament.

* *P* value was calculated by independent *t* test.

Table 3

The relationship between TAL injury and bony displacement measures.

	P value	OR	95% CI
LMD (mm)	.030*	2.199	1.081–4.474
ILM (mm)	.280	1.539	0.704–3.366
ELM (mm)	.362	0.725	0.363–1.448
Fracture gap (mm)	.345	1.485	0.654–3.369

CI = confidence intervals, ELM = external lateral mass displacement, ILM = internal lateral mass displacement, LMD = lateral mass displacement, OR = odds ratio, TAL = transverse atlantal ligament.
* *P* value was calculated by multivariable logistic regression analysis.

Table 5

Frequency analysis in isolated atlas bursting fractures with TAL injury vs TAL intact.

	TAL injury based on MRI	TAL intact based on MRI	$P<.001^*$
LMD ≥ 8.1 mm	9 (90%)	0 (0%)	9
LMD < 8.1 mm	1 (10%)	20 (100%)	21
	10	20	30

LMD = lateral mass displacement, MRI = magnetic resonance image, TAL = transverse atlantal ligament.
* *P* value was calculated by Chi-Squared test.

3.3. Comparison of radiologic parameters between patients who underwent surgery and patients who did not

Nine patients underwent surgery for isolated atlas burst fractures, and 21 did not. Among the 9 surgeries performed, 3 were OCF, 3 had C1/C2 fusion, and 3 had posterior C1 osteosynthesis. LMD (9.56 vs 4.03 mm, $P<.001$) and fracture gap (7.96 vs 4.01 mm, $P<.001$) were significantly higher in patients who underwent surgery. However, there were no significant differences between the surgery-receiving and non-surgery-receiving groups in terms of age, ADI, or BDI (Table 6).

3.4. Treatment outcome of the isolated atlas burst fracture – union versus nonunion

We examined the union state of isolated atlas burst fractures 6 months after the initial diagnosis. While 11 patients achieved union, 19 patients (63%) did not. Among several radiological parameters, the fracture gap (6.13 vs 3.60, $P=.023$) was significantly higher in patients who failed to achieve union than in those who successfully achieved union. No significant differences were seen in age (54.73 vs 47.91 years, $P=.297$), ADI (1.55 vs 1.34 mm, $P=.480$), LMD (6.45 vs 4.38 mm, $P=.139$), BDI (2.68 vs 2.44 mm, $P=.763$), ILM (24.44 vs 21.70 mm, $P=.102$), or ELM (50.74 vs 48.06 mm, $P=.111$) between the patients who did and did not achieve union (Table 7). Interestingly, while over half of patients failed to achieve union, no patient displayed instability at follow-up; C1/C2 stability was maintained well in all patients examined in this study.

4. Discussion

Atlas burst fractures occur when axial force is transmitted across the occipitocervical junction, resulting in a 4-part fracture (2 in the posterior arch and 2 in the anterior arch).[14] Unstable C1 burst fractures are an even more severe injury to the atlas that occurs when the TAL is also ruptured secondary to the extent of the spread of the C1 arch. According to Oda et al, high-velocity trauma is the most common cause of burst fractures of the atlas ring.[15] In that study, 56.7% (17 patients) of atlas burst fractures were caused by MVAs and 43.3% (13 patients) were a result of a fall from a significant height. However, in none of the cases were atlas burst fractures the result of a fall from a typical standing height. Our results were consistent with this finding, suggesting that atlas burst fractures require higher-energy injury mechanisms.

Identifying TAL injuries is an important prerequisite for determining the appropriate treatment strategy for patients with an isolated atlas burst fracture.[14] In the absence of a TAL injury, the fracture is regarded as stable, and conservative treatment is recommended. The presence of TAL injury indicates that the fracture is unstable and that surgical treatment is required. MRI is the established gold standard imaging modality for assessing TAL integrity.[6] However, MRI may not be available or of sufficient quality in every hospital. Fortunately, patients presenting with atlas fractures routinely undergo MRI at our institution, and we were able to obtain MRI images from all patients with atlas fractures. Using these images, we compared the radiologic parameters in patients with isolated atlas burst fractures with and without TAL injury. Radcliff et al previously reported no correlation between bony displacement and the presence of a TAL injury.[6] In addition, Dickman et al reported that LMD greater than 7 mm misses 61% of TAL injuries.[16] Perez-Orribo et al asserted that the rule of Spence is insufficiently sensitive to detect TAL injuries.[17] However, our results showed that there is a significant correlation between radiologic parameters, including LMD, ELM, ILM, and fracture gap, and the presence of a TAL injury. One explanation for our different findings is that previous researchers were unable to assess the TAL injuries of their examined patients using MRI. Previous researchers also

Table 4

Correlation analysis of radiologic parameters in patients with a C1 bursting fracture.

	ILM	ELM	Fracture Gap
LMD	CC = 0.661	CC = 0.705	CC = 0.840
P value	<0.001*	<0.001*	<0.001*

CC = correlation coefficient, ELM = external lateral mass displacement, ILM = internal lateral mass displacement, LMD = lateral mass displacement, TAL = transverse atlantal ligament.
* *P* value was calculated by Pearson correlation test.

Table 6

Differences in radiologic parameters according to the presence of surgical treatment.

	Presence of surgical treatment		
	No (n = 21)	Yes (n = 9)	*P* value
Age (yrs)	52.90 ± 17.29	50.67 ± 17.15	.747
ADI (mm)	1.30 ± 0.63	1.87 ± 0.99	.070
LMD (mm)	4.03 ± 2.32	9.56 ± 3.37	<.001*
BDI (mm)	3.61 ± 1.48	3.56 ± 1.46	.934
ILM (mm)	22.10 ± 3.95	26.56 ± 3.95	.008*
ELM (mm)	48.34 ± 3.90	53.06 ± 3.88	.005*
Fracture gap (mm)	4.01 ± 2.47	7.96 ± 2.28	<.001*

ADI = atlanto-dental interval, BDI = basion-dens interval, ELM = external lateral mass displacement, ILM = internal lateral mass displacement, LMD = lateral mass displacement.
* *P* value was calculated by independent *t* test.

Table 7

Differences of radiologic parameters between the patients that achieved union and those that did not.

	Union status of isolated atlas burst fracture		
	Nonunion (n=19)	Union (n=11)	*P* value
Age (yrs)	54.73±14.71	47.91±20.37	.297
ADI (mm)	1.55±0.83	1.34±0.70	.480
LMD (mm)	6.45±3.08	4.38±4.35	.139
BDI (mm)	2.68±1.85	2.44±1.69	.763
ILM (mm)	24.44±4.41	21.70±3.99	.102
ELM (mm)	50.74±3.56	48.06±5.36	.111
Fracture gap (mm)	6.13±2.87	3.60±2.62	<.023*

ADI=atlanto-dental interval, BDI=basion-dens interval, ELM=external lateral mass displacement, ILM=internal lateral mass displacement, LMD=lateral mass displacement.
* *P* value was calculated by independent *t* test.

included other combined fractures, such as odontoid fractures, in their datasets, while we included only isolated atlas burst fractures to reduce selection bias. Our results were consistent with those of Kim et al,[1] who determined that LMD at the time of presentation was significantly higher in patients with an unstable fracture. Our results confirm that LMD closely correlates with TAL injury in patients with an isolated atlas burst fracture; therefore, we recommend that LMD be used as a means of predicting the presence of a TAL injury in cases where an MRI is not available.

Another potentially important means of assessing TAL injuries is the measurement of ADI, although the relationship is controversial. Oda et al reported that ADI was the best diagnostic tool for transverse ligament function,[15] while Perez-Orribo et al determined that ADI was not sensitive enough to detect transverse ligament injuries.[17] In our study, ADI was higher in patients with TAL injury (1.84 vs 1.29 mm), but not so much so that the measure carried any statistical significance. We think that there was no significant difference in ADI according to the presence of TAL injury due to the absence of flexion-extension images taken immediately after injury, accounting for the risk of spinal cord injury.

There is an ongoing discussion within the treatment community concerning the benefits and drawbacks of surgical treatments, including OCF, C1/C2 fusion, and C1 osteosynthesis, and nonsurgical treatments of isolated unstable atlas burst fractures. Kim et al recently reported that most atlas burst fractures were managed non-surgically regardless of their stability.[1] In our study, we observed several cases that fell into this category. Although over half of the patients in our study (58.6%) failed to achieve union, none of our patients ultimately manifested instability on flexion-extension radiographs. This was true even for a patient who presented with isolated atlas burst fracture with TAL injury, but who rejected surgical treatment and was managed successfully with halo traction for 3 months (Figure 3).

Haus and Harris reported a case of nonoperative treatment of an unstable Jefferson fracture treated using a cervical collar.[18] In their study, the patient had only 3 mm of ADI, and they suggested that the residual stability was provided by an intact alar ligament and longitudinal part of the cruciate ligament and/or portions of facet capsules and scarring of the avulsed transverse ligament. Protective immobilization with a cervical collar produced sufficient long-term stability to enable bony fusion of the atlas fracture. This case report is consistent with our results, as far as most patients in our study had an ADI of less than 3 mm, and our patients achieved stability even though they failed to achieve union. These favorable results prompted us to begin favoring a novel less-invasive treatment approach, C1 osteosynthesis, in treating isolated atlas burst fractures. Historically, the surgical options for OCF or C1/C2 fusion were the preferred response to unstable atlas fractures in our institution; however, OCF, as reported by 2 out of 3 of our patients, was accompanied by a severe limitation in the neck's range of motion and induced many complications, such as difficulty in swallowing and adjacent segment degeneration.[19] In both cases, the patients requested

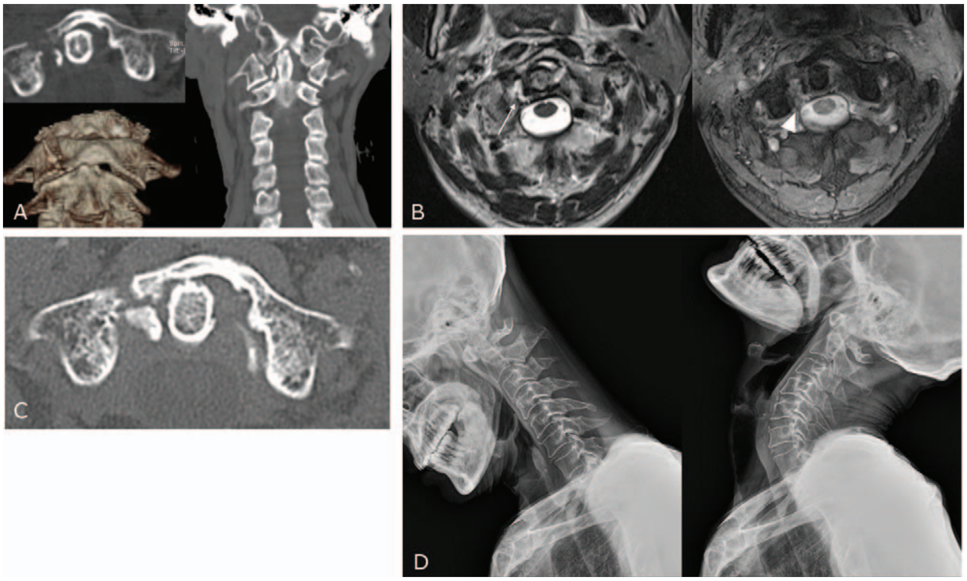

Figure 3. (A) Initial CT images showing fracture of both anterior and posterior arch of C1. (B) Initial MRI showing TAL tearing on T2 axial image (arrow) and T2 fat suppression image (arrowhead). CT image 6 months after trauma showing nonunion of the anterior arch of C1 (C), but no instability on a flexion/extension X-ray (D). CT=computed tomography, MRI=magnetic resonance image, TAL=transverse atlantal ligament.

that we remove the occipito-cervical instrumentation system, which we performed 2 years after their initial surgery. Fortunately, both patients were satisfied with the results of the metal removal surgery. This prompted us to favor C1 osteosynthesis in relevant cases, such as where an atlas burst fracture with TAL injury was present, but without rotational ligamentous injuries and ADI was less than 3 mm. C1 osteosynthesis resulted in successful outcomes. Our results are consistent with those of previous authors,[20,21] who have suggested that secondary stabilizers and restored anatomical congruence play a role in stabilizing the C1/C2 joint in addition to the TAL, and that these structures, in conjunction with the reconstruction of the axial tension band through reduction, were sufficient to prevent C1/C2 instability. Our findings are also consistent with their suggestion that TAL incompetence may not be a contraindication for C1 osteosynthesis for atlas fracture treatment. Therefore, we believe that, regardless of the TAL injury type, less invasive C1 osteosynthesis should be performed to set an incompetent TAL and treat atlas burst fractures.

The strength of our study is that this is the first study to determine the efficacy of diagnosing TAL injuries using MRI in all patients with isolated atlas burst fracture because we routinely evaluate the integrity of the transverse ligament in patients with an atlas burst fracture using MRI in our department. However, our study is limited by the inclusion of only a small number of patients and its retrospective design, both of which potentially bias its findings. To our disappointment, we were also unable to consistently obtain lateral flexion/extension views of the severe trauma. These limitations can only be overcome in a prospective, large-scale clinical study.

5. Conclusion

MRI is the preferred method for identifying TAL injuries in patients with atlas fractures. Our results show that LMD, among various radiologic parameters, is closely correlated with the presence of a TAL injury, as patients with an LMD greater than 8.1 mm are more likely to have a TAL injury in the case of atlas burst fractures. We conclude that LMD is a good method for predicting the presence of a TAL injury if MRI is not available.

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Author contributions

Conceptualization: Youngmin Oh, Jongpil Eun
Data curation: Youngmin Oh
Funding acquisition: Youngmin Oh
Investigation: Jongpil Eun, Youngmin Oh
Methodology: Youngmin Oh
Writing – original draft: Jongpil Eun, Youngmin Oh
Writing – review and editing: Jongpil Eun, Youngmin Oh
Conceptualization: Jongpil Eun, Youngmin OH.
Data curation: Youngmin OH.
Funding acquisition: Youngmin OH.
Investigation: Jongpil Eun, Youngmin OH.
Methodology: Youngmin OH.
Writing – original draft: Jongpil Eun, Youngmin OH.
Writing – review & editing: Jongpil Eun, Youngmin OH.

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