CLINICAL ARTICLE

Proposal of New Radiological Classification and Treatment Strategy for Transverse Fractures of the C2 Axis Body

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Objective: To investigate the characteristics of transverse fractures of the C2 axis body diagnosed on sagittal computed tomography (CT) and to propose new classification and appropriate treatment strategies.

Methods: A retrospective study was performed by enrolling 49 patients (26 men and 23 women) with transverse fractures of the C2 axis body who were treated at four national trauma centers of tertiary university hospitals from January 2000 to December 2017. The mean age of the patients was 60.8 years (ranging from 21 to 90 years). We classified 49 transverse fractures of the C2 body into three types based on fracture trajectories involving superior articular facet (SAF) and lateral cortex (LC) of the C2 body on coronal CT as follows: Type 1, involvement of C2 SAF on both sides; Type 2, unilateral involvement of C2 SAF on one side and LC on the other side; Type 3, involvement of LC on both sides. The characteristics, treatment methods, and results of 49 transverse fractures of the C2 body were analyzed. Mean follow-up was 12.6 months (ranging from 12 to 26 months).

Results: Twenty-six (53.1%) patients were Type 1, 21 (42.9%) were Type 2, and 2 (4.0%) were Type 3. Correlation coefficients for intra-observer and inter-observer reliabilities of classification were 0.723 and 0.598 (both, $P < 0.001$), respectively. About 40.8% (7 Type 1 and 13 Type 2) of the patients had fracture displacement >3 mm; Incidence of fracture displacement >3 mm was higher in Type 2 than Type 1 (61.9% *vs* 26.9%, $P < 0.05$). About 79.6% (20 Type 1, 17 Type 2 and 2 Type 3) of the patients were treated conservatively, and 20.4% (6 Type 1 and 4 Type 2) underwent surgery. At last follow-up, 47 out of 49 patients achieved fusion; overall fusion rate was 95.9%. All conservatively treated Type 1 and Type 3 patients achieved fusion. Out of 17 conservatively treated Type 2 patients, 15 achieved fusion but two developed nonunion; however, two nonunion patients opted not to undergo surgery. Subgroup analysis showed that Philadelphia brace caused nonunion significantly in fracture displacement >3 mm compared to Minerva brace/Halovest (100% *vs* 0%, $P < 0.05$). All surgically treated Type 1 and 2 patients achieved fusion. In terms of clinical outcomes, neck pain visual analog scale and neck disability index were significantly improved (both, $P < 0.01$). According to Odom's criteria, 93.9% (46/49) of the patients achieved satisfactory outcomes. No major complications occurred.

Conclusions: The majority of transverse fractures of C2 body can be treated conservatively. However, surgery or rigid Minerva brace/Halovest should be considered for Type 2 transverse fractures of the C2 body with fracture displacement >3 mm.

Key words: Axis; Body; Classification; Fracture; Transverse; Treatment

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Introduction

Fractures of the C2 axis are common traumatic injuries of the upper cervical spine, representing 10%–20% of all cervical spine injuries[1–3]. In general, these fractures are divided into three distinct types: dens fractures, Hangman's fractures, and miscellaneous fractures (or non-dens/non-Hangman's fractures) that involve the C2 body or lateral mass[4,5]. Due to the peculiar anatomical and biomechanical characteristics of the C2 vertebra, multiple and diverse fracture patterns of the C2 body can occur[1–3]. Therefore, many cases of C2 body fractures cannot be classified according to the existing fracture classifications and specific subtypes of C2 body fractures need to be classified for optimal management of each specific injury[3,6–8]. Transverse fracture of the C2 body is one of the C2 body fractures and also can be seen in pedicle, lateral mass, transverse foramen, and pars interarticularis[1]. However, little information is available about the characteristics of transverse fractures of C2 body that can affect treatment, outcome, and prognosis. To date, a few classifications of transverse fractures of C2 body have been previously described[6–11], but still it is difficult to make a proper treatment decision for these types of fractures.

Fracture types of C2 body can rarely be differentiated on the basis of a single imaging modality[6]. Introduction of computed tomography (CT) scan has provided more precise and detailed information about fractures of the spine than previous radiographic examinations. With the application of CT scan, complex C2 body fractures have been able to be depicted and identified accurately[6,12,13]. Accordingly, more accurate diagnoses of and treatment plans for transverse fractures of the C2 body are possible. Therefore, we performed the current study to investigate the characteristics of transverse fractures of C2 body based on our new radiologic classification developed by considering fracture patterns on coronal CT and to propose appropriate treatment strategies.

Materials and Methods

Inclusion and Exclusion Criteria

A total of 49 patients with transverse fractures of the C2 body, who were treated at four national trauma centers of tertiary university hospitals between January 2000 and December 2017, were included in the study. The inclusion criteria were as follows: (i) a history of acute trauma; and (ii) transverse fracture of the C2 body diagnosed on lateral X-ray and sagittal CT scans. The exclusion criteria were as follows: (i) a history of previous surgery or fracture; and (ii) the presence of infection, tumor, or ankylosing spondylitis.

New Radiologic Classification for Transverse Fractures of the C2 Body

The authors developed a new radiologic classification, named as Park's classification, for transverse fractures of the C2 body. The Park's classification criteria are based on whether the fracture trajectories involve the C2 superior articular facet (SAF) and lateral cortex (LC) on coronal CT scans and consists of three types. All 49 patients with transverse fracture of the C2 body (Fig. 1A) were stratified into three types as follows: Type 1, fracture trajectories that involve the C2 superior articular facet (SAF) on both sides (Fig. 1B); Type 2, fracture trajectories that involve the SAF on one side and the lateral cortex (LC) on the other side (Fig. 1C); Type 3, fracture trajectories that involve the LC on both sides (Fig. 1D). Two spine surgeons with more than 10 years of clinical experience performed the classification twice at intervals of 2 weeks. Two spine surgeons were blinded to the identity of the cases, and the original findings were not disclosed during the second round.

Analysis of Conservative and Surgical Treatment Methods

Plain radiographs, CT scans, magnetic resonance imaging (MRI), and medical records for 49 patients with transverse fractures of the C2 body were retrospectively reviewed for analyzing the fracture characteristics and conservative and surgical treatment methods for each three type of transverse fractures of the C2 body.

Radiologic Assessment of Fracture Displacement and Fusion Status

Fracture Displacement

The amount of fracture displacement was measured by the distance between anterior cortexes of transverse fracture fragment and remaining C2 body.

Fusion Status

The fusion status was defined by the evidence of bone trabeculae crossing the fracture line in lateral radiograph and/or CT scans. Fracture stability was determined by the absence of secondary displacement of the C2 body in flexion and extension lateral radiographs.

Assessment of Clinical Outcomes

Neck Pain Visual Analog Scale (VAS)

Neck pain VAS is a continuous scale to measure subjective pain intensity. For pain intensity, the scale is most commonly anchored by "no pain" (score of 0) and "worst imaginable pain" (score of 10). Neck pain VAS was used to evaluate clinical outcome for pain improvement after treatment.

Neck Disability Index (NDI)

NDI is a self-report questionnaire used to determine how neck pain affects a patient daily life and to assess the self-rated disability of patients with neck pain. There are 10 questions each scored with a possible 0–5 value with the larger number indicating a higher self-reported disability status. The score on this questionnaire can range from 0–50. Higher

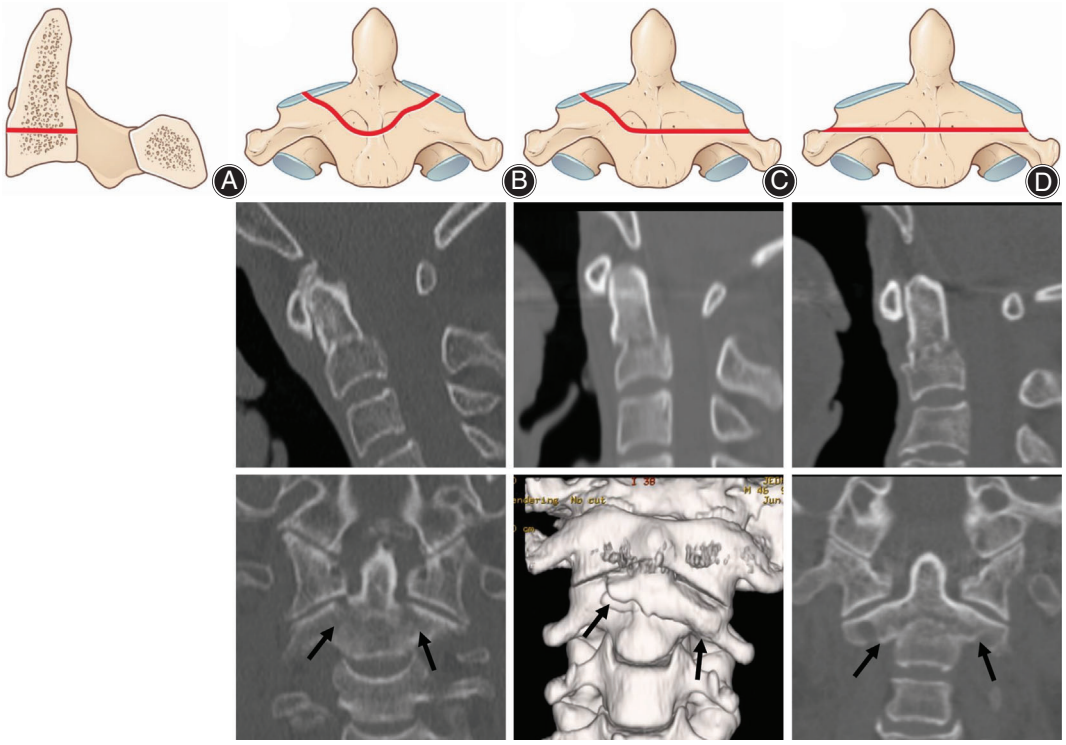

Fig 1 New radiologic classification for transverse fractures of the C2 body (Park's classification). Transverse fracture of C2 body on lateral and sagittal computed tomography (CT) (A); Type 1 fracture that involve the C2 superior articular facet (SAF) on both sides (dark arrows) (B); Type 2 fracture that involve the SAF on one side and the lateral cortex (LC) on the other side (dark arrows) (C), and Type 3 fracture that involve the LC on both sides (dark arrows) (D).

scores reflecting higher interference of pain with daily activities.

Odom's Criteria

Odom's criteria are a widely used, 4-point rating scale for assessing the clinical outcome after cervical spine surgery (Table 1). The rating is performed by treating spine surgeon. Excellent and good ratings are classified into satisfactory outcomes.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics for Windows/Macintosh, Version 22.0 (IBM Corp., Armonk, NY, USA). The difference between initial and last follow-up neck pain VAS and NDI was analyzed by paired *t*-test. The chi-square test was used for comparisons of variables between the two groups. The correlation coefficients for intra-observer and inter-observer reliabilities of new Park's classification were estimated using the Pearson correlation test. The level of significance was set at $P < 0.05$.

TABLE 1 Odom's criteria

Grading	Definition
Excellent	All preoperative symptoms and abnormal findings improved
Good	Minimal persistence of preoperative symptoms Abnormal findings improved
Fair	Definite relief of some preoperative symptoms Other symptoms slightly improved
Poor	Symptoms and signs unchanged or worse

Approval of the Institutional Review Board (IRB)

This multicenter retrospective study was approved by the institutional review board of the corresponding author's university hospital, and the requirement for informed written consent from the patients for participation in this study and use of accompanying images was waived.

Results

Demographic Data

Demographic data, including fracture type, injury mechanism, and neurologic status, are summarized in Table 2. The mean age of the patients at the time of injury was 60.8 years (range: 21–90 years). Twenty-six patients were male, and 23 patients were female. The mean follow-up period was 12.6 months (range: 12–26 months). Regarding the injury mechanism, 22 patients (44.9%) were involved in a traffic accident, 12 patients (24.5%) experienced a fall from a

TABLE 2 Demographic data of 49 cases with transverse fracture of the C2 body

Age (years)	60.8 ± 15.9 (range: 21–90)
Sex	Males: 26, Females: 23
Follow-up (months)	12.6 ± 2.6 (range: 12–26)
Fracture type	
Type 1	26 (53.1%)
Type 2	21 (42.8%)
Type 3	2 (4.1%)
Injury mechanism	
Traffic accident	22 (44.9%)
Falling down	12 (24.5%)
Slipping down	13 (26.5%)
Blunt trauma	2 (4.1%)
Neurologic status	
Normal	49 (100%)
Deficit	

height, 13 patients (26.5%) slipped, and two patients (4.1%) experienced blunt trauma. Neurologic status upon admission revealed that all 49 patients had normal neurologic function.

New Radiologic Classification of Transverse Fractures of the C2 Body

Among the 49 patients with transverse fracture of the C2 body, 26 (53.1%) were Type 1 fractures, 21 (42.8%) were Type 2 fractures, and two (4.1%) were Type 3 fractures. Correlation coefficient for intra-observer reliability of new Park's classification was 0.723 ($P < 0.001$), which indicated a strong correlation. Correlation coefficient for inter-observer reliability of new Park's classification was 0.598 ($P < 0.001$), which indicated a moderate correlation.

Conservative and Surgical Treatment Methods

Treatment methods for transverse fractures of the C2 body are also summarized in Table 3. In terms of treatment methods, 79.6% (39/49) of all patients were treated conservatively, and the remaining 20.4% (10/49) underwent surgery. In Type 1 fracture, 76.9% (20/26) of the patients were treated conservatively, and the remaining 23.1% (6/26) underwent surgery. In Type 2 fracture, 80.9% (17/21) of patients received conservative treatment, while the remaining 19.1% (4/21) underwent surgery. The difference in treatment methods was not significant between Type 1 and 2 fractures ($P = 0.601$). For Type 3 fracture, two patients (100%) were treated conservatively. In terms of conservative treatment methods, while 55.0% of Type 1 patients wore a Philadelphia brace, 82.3% of Type 2 patients wore a rigid Minerva brace/Halovest. The difference in conservative treatment methods was significant between Type 1 and 2 fractures ($P < 0.05$). In terms of surgical treatment methods, while 100% (6/6) of Type 1 patients underwent anterior dens screw fixation, 50.0% (2/4) of Type 2 patients underwent anterior dens screw fixation and the remaining 50.0% (2/4) underwent posterior C1-2 fusion. The difference in surgical treatment methods was not significant between Type 1 and 2 fractures ($P = 0.133$).

Radiologic Outcomes of Fracture Displacement and Fusion Status

Fracture Displacement

Detailed data on fracture displacement of transverse fractures of the C2 body are summarized in Table 3. Overall, 40.8% (20/49) of the patients had fracture displacement >3 mm, and the remaining 59.2% (29/49) had fracture displacement ≤3 mm. In Type 1 fracture, 26.9% (7/26) of the patients had fracture displacement >3 mm, while 73.1% (19/26) had fracture displacement ≤3 mm. For Type 2 fracture, 61.9% (13/21) had fracture displacement >3 mm, while the remaining 38.1% (8/21) demonstrated fracture displacement ≤3 mm. The difference in fracture displacement >3 mm and ≤3 mm was significant between the two types ($P < 0.05$). In

TABLE 3 Fracture displacement and treatment methods of transverse fractures of C2 body

	Type 1 (N = 26)	Type 2 (N = 21)	Type 3 (N = 2)	*P*-value
Fx displacement				<0.05*
>3 mm	7/26 (26.9%)	13/21 (61.9%)	-	-
≤3 mm	19/26 (73.1%)	8/21 (38.1%)	2/2 (100%)	-
Tx methods				0.601#
Conservative Tx	20/26 (76.9%)	17/21 (80.9%)	2/2 (100%)	-
Surgical Tx	6/26 (23.1%)	4/21 (19.1%)	-	-
Conservative Tx				<0.05*
P-brace	11/20 (55.0%)	3/17 (17.7%)	-	-
M-brace/H-vest	9/20 (45.0%)	14/17 (82.3%)	2/2 (100%)	-
Surgical Tx				0.133#
Anterior	6/6 (100%)	2/4 (50.0%)	-	-
Posterior	-	2/4 (50.0%)	-	-

Fx, fracture; H-vest, Halovest; M-brace, Minerva brace; P-brace, Philadelphia brace; Tx, treatment. The *P*-value was calculated using a chi-square test; * statistically significant between Type 1 and Type 2;; # not statistically significant between Type 1 *vs* Type 2.

TABLE 4 Overall fusion status of transverse fractures of the C2 body

	Total (N = 49)	Type 1 (N = 26)	Type 2 (N = 21)	Type 3 (N = 2)	*P*-value
Conservative Tx					0.545#
Union	37/39 (94.9%)	20/20 (100%)	15/17 (88.2%)	2/2 (100%)	
Nonunion	2/39 (5.1%)		2/17 (11.8%)*		
Surgical Tx					
Union	10/10 (100%)	6/6 (100%)	4/4 (100%)		
Nonunion					

Tx, treatment; * fracture displacement >3 mm that was treated by Philadelphia brace; The *P*-value was calculated using a chi-square test; # not statistically significant between Type 1 *vs* Type 2.

Type 3 fracture, two patients (100%) had fracture displacement ≤3 mm.

Fusion Status

Overall fusion status of transverse fractures of the C2 body are summarized in Table 4. At last follow-up, 47 out of 49 patients achieved fusion; overall fusion rate was 95.9%. About 94.9% (37/39) of conservatively treated patients achieved fusion. All conservatively treated Type 1 (100%, 20/20) and Type 3 (100%, 2/2) patients achieved fusion. However, out of 17 conservatively treated Type 2 patients, 15 (88.2%) achieved fusion (Fig. 2) but 2 (11.8%) developed nonunion (Fig. 3). On the contrary, all surgically treated Type 1 (100%, 6/6) and Type 2 (100%, 4/4) patients achieved fusion by anterior dens screw fixation (Fig. 4) or posterior C1-2 fusion (Fig. 5).

We analyzed the fusion status of conservative treatments for transverse fractures of the C2 body depending on amount of fracture displacement >3 mm and ≤3 mm (Table 5). Irrespective of fracture types, 100% (27/27; 17 Type 1, 8 Type 2, and 2 Type 3) of transverse fractures with fracture displacement ≤3 mm achieved fusion. In fracture displacement >3 mm, 100% (3/3) of Type 1 fractures achieved fusion. While 77.8% (7/9) of Type 2 fractures achieved fusion, 22.2% (2/9) of Type 2 fractures developed nonunion; however, two nonunion patients opted not to undergo a surgery. Subgroup analysis of fusion status for conservatively treated Type 2 fractures showed that Philadelphia brace treatment caused nonunion significantly in Type 2 patients with fracture displacement >3mm compared to Minerva brace/Halovest (100% *vs* 0%, $P < 0.05$) (Table 6).

Clinical Outcomes of Neck Pain VAS, NDI, and Odom's Criteria

Overall clinical treatment outcomes of transverse fractures of the C2 body are summarized in Table 7. At last follow-up, neck pain VAS significantly decreased compared to initial presentation (5.9 ± 1.5 *vs* 1.8 ± 0.6, $P < 0.01$). The NDI significantly decreased compared to initial presentation (42.9 ± 6.1 *vs* 13.3 ± 3.6, $P < 0.01$). According to Odom's criteria, 93.9% (46/49) of the patients achieved satisfactory outcomes including 26 excellent and 20 good outcomes. No major complications occurred during the treatments.

Discussion

New Radiologic Classification of Transverse Fractures of the C2 Body

Compared to dens fractures and Hangman's fractures, C2 body fractures are not commonly recognized C2 fractures and have a variety of presentation[10–13]. Many studies on C2 dens fractures and hangman's fractures have been conducted over the years, so classification and treatment strategies for dens fractures and hangman's fractures are relatively well-established[4,5]. However, few studies have investigated C2 body fractures and many cases of them cannot be framed within the existing classification[6,9]. Therefore, classification and treatment strategies for C2 body fractures are not clearly established and should be individualized due to the anatomical peculiarity of C2 body. Transverse fractures of the C2 body are a form of C2 body fractures diagnosed using lateral radiographs and sagittal CT scans.

In this study, we proposed a new classification (Park's classification) consisting of three types of transverse fractures of the C2 body for the first time, based on fracture involvement of the SAF and the LC of the C2 body as seen on coronal CT scans as follows: Type 1, fractures that involve the C2 SAF on both sides; Type 2, fractures that involve the SAF on one side and the LC on the other side; Type 3, fractures that involve both sides of the LC. Type 1 and Type 2 fractures accounted for 53.1% and 42.9%, respectively, while Type 3 fracture was rare, making up just 4% of the sample. Correlation coefficients for intra-observer and inter-observer correlations of our new classification were 0.723 and 0.598, which mean that new Park's classification for transverse fractures of the C2 body was accurate.

In 1974, Anderson and D'Alonzo[14] modified Schazker's classification of odontoid fractures extending the vertebral body (Type 3 fracture), which encompassed a heterogeneous collection of morphologically different fractures[15]. In 1994, Benzel *et al.*[6] classified fractures of the C2 body into three types based on fracture orientation: coronal,

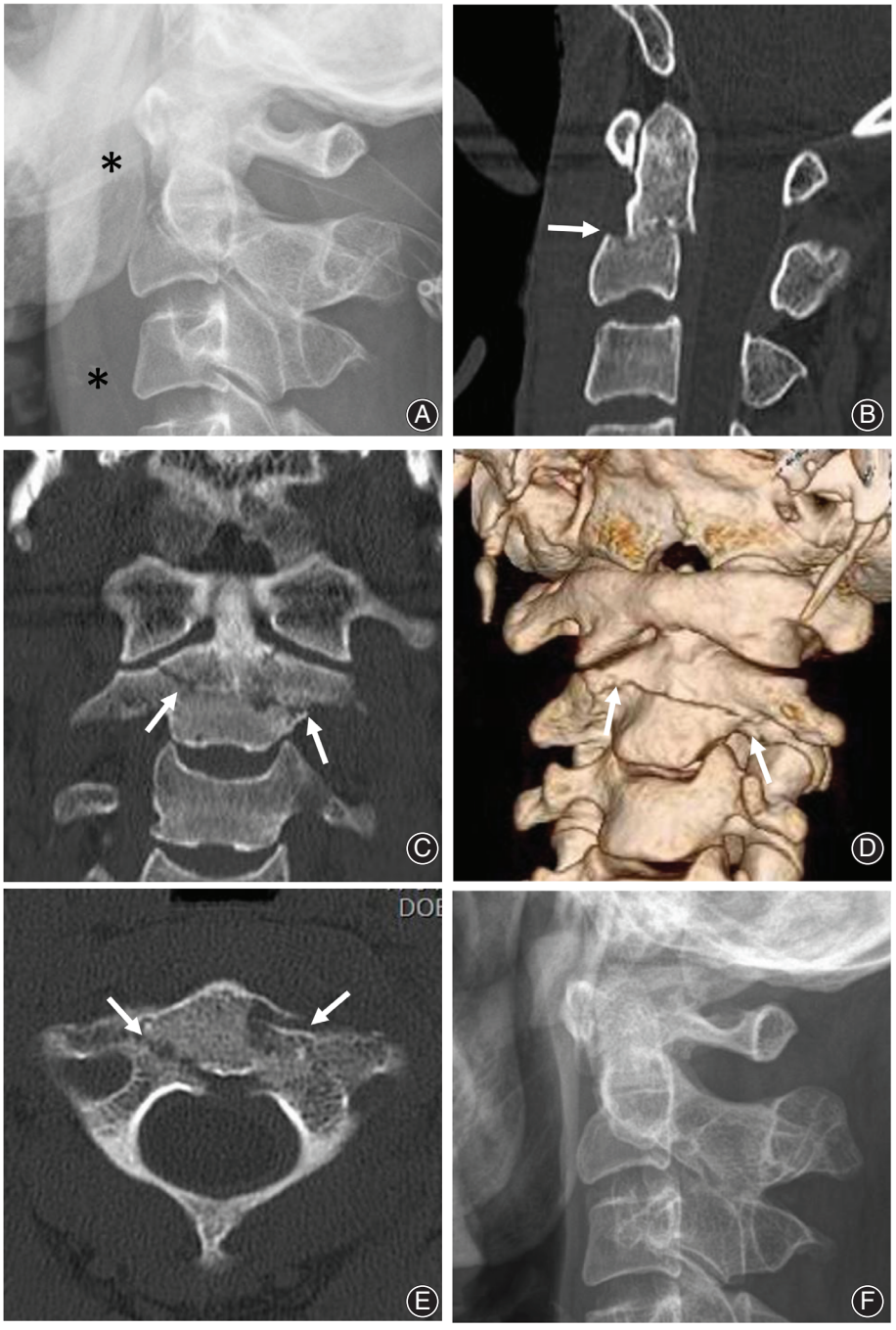

Fig 2 Initial lateral radiograph (A) and sagittal (B) computed tomography (CT) scans showing prevertebral soft tissue swelling (asterisks) and transverse fracture of the C2 body (white arrows). Coronal CT (C and D) scans clearly showing Type 2 transverse fracture of the C2 body. (white arrows). Axial CT (E) showing bilateral pedicle fractures (white arrows). At 17 months after Halovest application, follow-up lateral radiograph (F) showing a solid fusion of transverse fracture of the C2 body.

sagittal, and horizontal. The horizontal fracture is the previously described Type 3 dens fracture. In 2005, Grauer *et al.*[8] proposed a new classification of dens fractures by modifying Type 3 dens fracture proposed by Anderson and D'Alonzo. In Grauer *et al.*'s Type 3 fractures, the fracture trajectory includes the C2 SAF. To clarify, a Type 1 transverse fracture in our classification system is similar to Type 3 dens fracture under Anderson and D'Alonzo classification and Grauer *et al.*'s modified classification system. Both fracture lines involve the C2 SAF. A Type 3 transverse fracture in our classification is similar to the fracture described by Fujimura *et al.*[7]

Conservative and Surgical Treatment Methods

Transverse fracture of the C2 body can be treated either conservatively or surgically considering fracture type and amount of fracture displacement[16–25]. Fujimura *et al.*[7] reported that many C2 body fractures were inherently stable

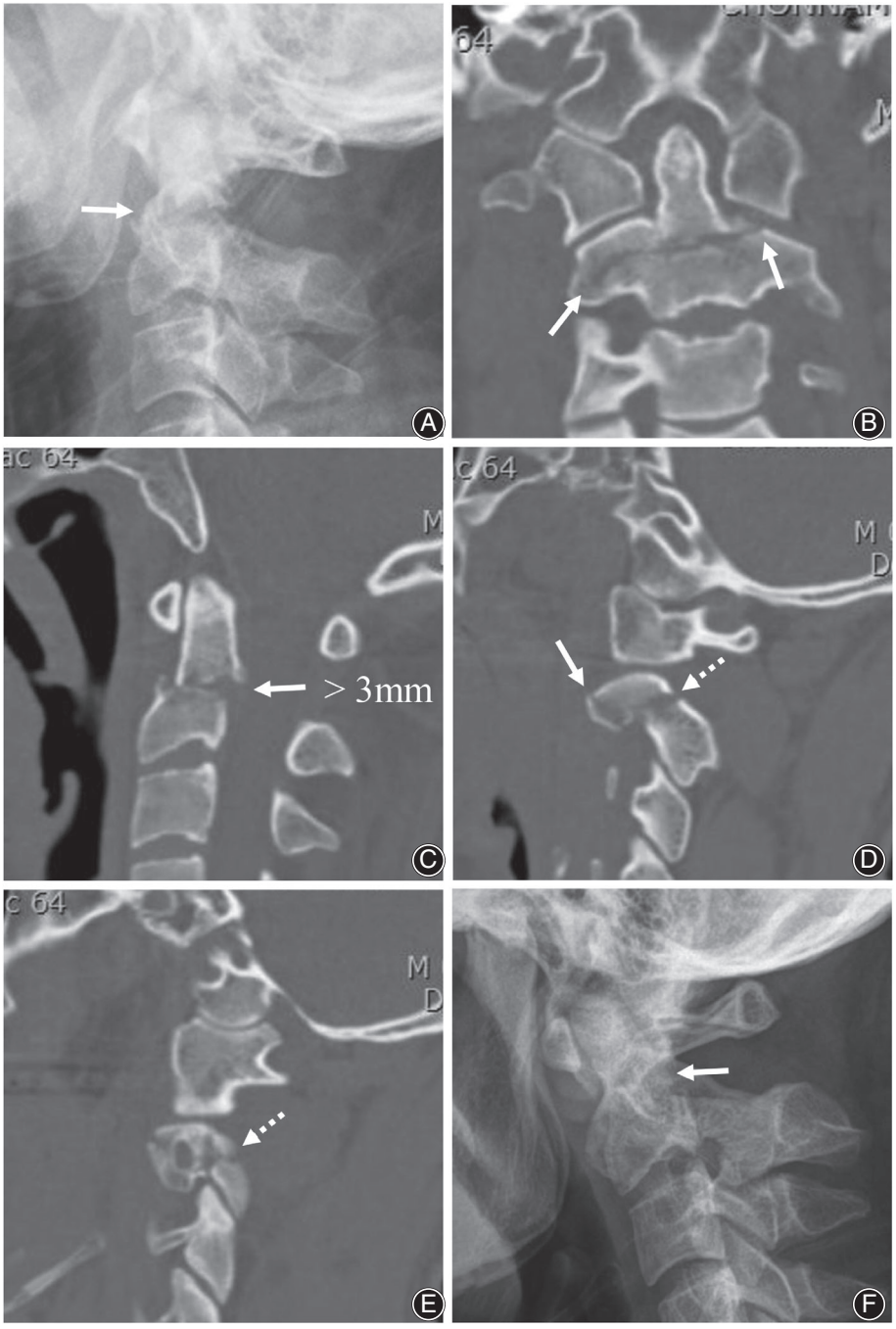

Fig 3 Initial lateral radiograph (A), coronal (B), and sagittal (C) computed tomography (CT) scans showing Type 2 transverse fracture of the C2 body (white arrows) with posterior displacement >3 mm. Parasagittal CT scans (D and E) showing superior articular facet (white arrows) and pars interarticularis (dotted white arrow) fractures. At 12 months' follow-up after Philadelphia brace, lateral radiograph (F**)** showing a kyphotic nonunion (white arrow) of transverse fracture of the C2 body.

injuries, so they routinely recommended nonoperative treatment as the initial therapy. Their two cases of conservatively treated transverse fracture achieved bone union without any sequelae. In this study, the percentage of conservative treatments applied in Type 1 and Type 2 fractures was similar (76.9% *vs* 80.9%, $P = 0.601$). However, while 55% of Type 1 fractures used a Philadelphia brace, 82.3% of Type 2 fracture patients were prescribed a Minerva brace/Halovest. The difference in conservative treatment methods was statistically significant between Type 1 and Type 2 fractures ($P < 0.05$). It is thought that higher incidence of fracture displacement >3 mm in Type 2 fracture patients can be attributed to greater use of Minerva brace/Halovest for Type 2 fracture patients.

Fracture Displacement

Twenty-one patients (42.9%) with transverse fractures of the C2 body had a fracture displacement >3 mm. An approximately 2.3 times higher incidence of fracture displacement >3 mm was observed in Type 2 fractures than in Type 1 fractures (61.9% *vs* 26.9%, $P < 0.05$). Two Type

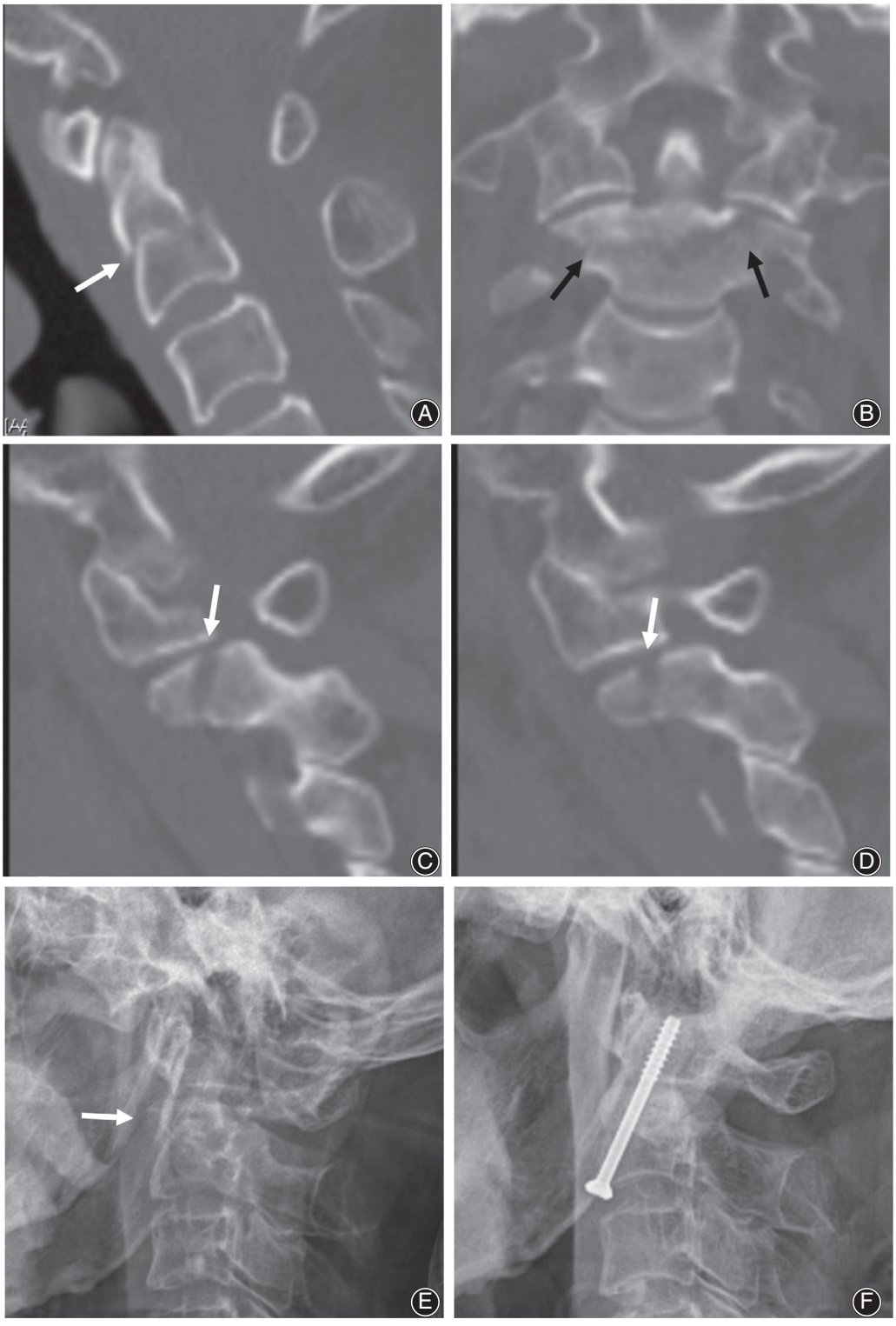

Fig 4 Sagittal (A) and coronal (B) computed tomography (CT) scans showing Type 2 transverse fracture of the C2 body (white and dark arrows). Right and left parasagittal (C and D) CT scans showing fractures of both superior articular facet (white arrows). Initial lateral radiograph (E) showing transverse fracture (white arrow) of the C2 body. At 12 months' follow-up after dens screw fixation, lateral radiograph (F) showing a fusion of transverse fracture of the C2 body.

3 fractures had a fracture displacement ≤3 mm. This finding suggests that Type 2 fractures may be more severe and unstable than Type 1 and 3 fractures, and the probability of nonunion may be higher.

Fusion Status

In terms of fusion rate, 94.7% (36/38) of conservatively treated transverse fractures of C2 body achieved solid fusion, which is consistent with the findings of previous studies[16–19].

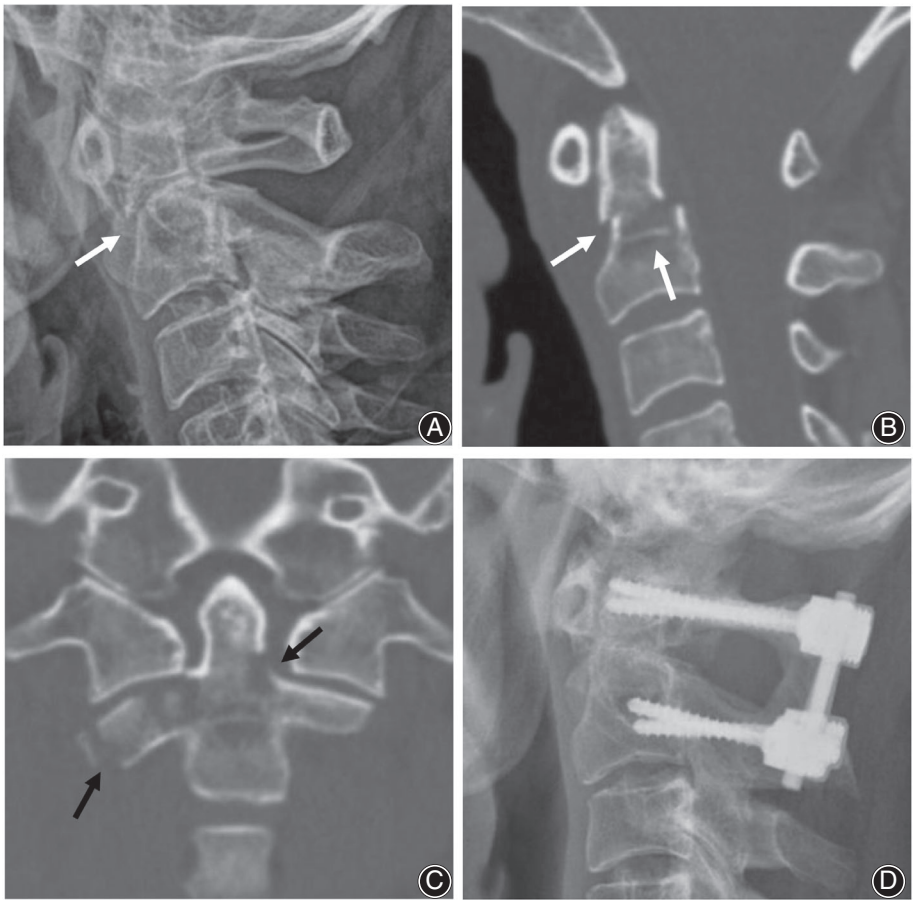

Fig 5 Preoperative lateral radiograph (A) and sagittal (B) computed tomography (CT) scan showing transverse fracture of the C2 body with anterior displacement (white arrows). Coronal CT (C) scan showing Type 2 transverse fracture of the C2 body (dark arrows) with right pedicle and superior articular facet (SAF) fractures. At 2 years after posterior C1-2 fusion, follow-up lateral radiograph (D) showing a fusion of transverse fracture of the C2 body.

Irrespective of fracture types, all conservatively treated transverse fractures with fracture displacement ≤3 mm achieved fusion. However, in fracture displacement >3 mm, 2 Type 2 patients developed nonunion after using a Philadelphia brace.

According to subgroup analysis, the Philadelphia brace caused nonunion significantly compared to the rigid Minerva brace/Halovest in Type 2 fractures with fracture displacement >3 mm. These results suggest that surgery or a rigid Minerva brace/Halovest should be considered for Type 2 transverse fractures of the C2 body with fracture displacement >3 mm.

Zhang *et al.*[12] retrospectively analyzed 28 cases with C2 body fractures. Thirteen cases were successfully managed conservatively, while the remaining 15 cases were successfully treated surgically. Among these surgically treated patients, two cases with transverse fractures were treated with posterior C1-2 pedicle screw fixation and fusion. They concluded that conservative treatment is still the primary management strategy for most C2 body fractures. However, for patients with obvious adjacent joint instability, irreducible displaced SAF fracture, or fracture resulting in spinal cord compression, surgical intervention

TABLE 5 Fusion status of conservative treatments for transverse fractures of the C2 body depending on amount of fracture displacement >3 mm and ≤3 mm

	Type 1 (N = 20)	Type 2 (N = 17)	Type 3 (N = 2)	*P*-value
Fx displacement > 3 mm				0.545#
Union	3/3 (100%)	7/9 (77.8%)	-	-
Nonunion	-	2/9 (22.2%)*	-	-
Fx displacement ≤ 3 mm				
Union	17/17 (100%)	8/8 (100%)	2/2 (200%)	-
Nonunion	-	-	-	-

Fx, fracture; * treated by Philadelphia brace; The *P*-value was calculated using a chi-square test; # not statistically significant between Type 1 *vs* Type 2.

TABLE 6 Subgroup analysis of fusion status for conservatively treated Type 2 transverse fractures of the C2 body depending on type of brace

	Conservatively treated Type 2 fractures (N = 17)		
	Philadelphia brace (N = 3)	Minerva brace/ Halovest (N = 14)	*P*-value
Fx displacement > 3 mm			<0.05*
Union		7/7 (100%)	
Nonunion	2/2 (100%)		
Fx displacement ≤ 3 mm			
Union	1/1 (100%)	7/7 (100%)	
Nonunion			

Fx, fracture; The *P*-value was calculated using a chi-square test; * statistically significant between Philadelphia brace and Minerva brace/Halovest.

TABLE 7 Overall clinical treatment outcomes of transverse fractures of the C2 body

	Initial (N = 49)	Last follow-up (N = 49)	*P*-value
Neck pain VAS	5.9 ± 1.5	1.8 ± 0.6	<0.01
NDI	42.9 ± 6.1	13.3 ± 3.6	<0.01
Odom's criteria			
Excellent	-	26 (53.1%)	-
Good	-	20 (40.8%)	-
Fair	-	2 (4.1%)	-
Poor	-	1 (2.0%)	-

NDI, neck disability index; VAS, visual analog scale; The *P*-value was calculated using a paired T-test.

is almost always necessary based on the inherently different fracture pattern.

In this study, 80.0% (8/10) of surgically treated transverse fractures of C2 body underwent C1-2 motion-preserving surgery of 8 dens screw fixation. In terms of fusion rate, 100% (10/10) of surgically treated patients achieved solid fusion. The C2 body mainly consists of cancellous bone, and its healing potential is therefore considered to be high. Therefore, we carefully recommend that C1-2 motion-preserving surgery should be considered for transverse fractures of the C2 body before C1-2 fusion surgery if possible due to the high healing potential of the C2 body.

Clinical Outcomes of Neck Pain VAS, NDI, and Odom's Criteria

Overall clinical treatment outcomes of transverse fractures of the C2 body were excellent in our study. At last follow-up, neck pain VAS and NDI significantly decreased compared to initial presentation. According to Odom's criteria, 93.9% of the patients achieved satisfactory outcomes. In addition, no major complications occurred during the treatments. We believe that high overall fusion rate of 95.9% and C1-2 motion-preserving surgery contributed to obtaining satisfactory treatment outcomes in transverse fractures of the C2 body.

Weakness and Strength of the Study

The primary weakness of this study was its retrospective multicenter design. Also, the study results may be influenced by selection bias because the treatment in each case was chosen according to the surgeon's discretion. However, to the best of our knowledge, our study is the largest case series to investigate transverse fractures of C2 body.

Conclusions

We proposed a new radiologic classification (Park's classification) for transverse fractures of the C2 body. And our results suggest that the majority of transverse fractures of the C2 body can be treated conservatively. However, surgery or a rigid Minerva brace/Halovest should be considered for Type 2 transverse fractures of the C2 body with fracture displacement >3 mm.

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