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Morphological Features and Clinical Results of C2 Vertebral Body Fractures

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Abstract: *Type of study:* Retrospective study. *Objectives:* To classify and analyze the morphological patterns of vertebral body fractures and report the clinical results. *Summary of literature review:* There have not been many reports on the classification of vertebral body fractures and treatment results, and it remains a matter of debate. *Materials and methods:* Among 107 patients diagnosed with an axis fracture from 2005 to 2019, 53 patients with fracture involving the vertebral body were selected. After the exclusion of 9 patients with a history of cervical spine surgery or who were lost to follow-up, 44 consecutive patients were enrolled in this retrospective study. Patients were classified into 5 groups (coronal, sagittal, transverse, avulsion, and complex) according to the main fracture line. The demographic data, injury mechanism, discoligamentous injury, combined injury, neurological symptoms, and clinical treatment results were analyzed. *Results:* Patients' average age was 61.7 years (range, 25–81 years). 24 patients were male and 20 were female. The average follow-up period was 14.2 months (range, 7–33 months). The coronal, sagittal, transverse, avulsion, and complex groups contained 5, 5,8, 7, and 19 patients, respectively. Six patients were injured by slip-down accidents, 12 patients by falling height, and 26 patients by traffic accidents. Eighteen patients were presented with a discoligamentous injury. Twenty-five patients showed a combination of fractures of cervical vertebrae and bones. Thirteen patients presented neurological symptoms. 16 patients were treated with a neck collar and 28 patients were treated with a halo-vest. Two patients eventually required surgical fusion because union was not achieved with conservative management. In the final follow-up, all neurological symptoms were resolved; however, 4 patients still complained of a mild tingling sensation in the upper extremity. Pin site infection occurred in 3 patients who were treated with a halo-vest, but it was controlled after antibiotic administration. *Conclusion:* Vertebral body fractures accounted for almost 50% of axis fractures in this study. Vertebral body fractures can be classified into 5 groups (coronal, sagittal, transverse, avulsion, and complex) according to the morphological pattern. Non-operative management can be a reasonable treatment option with good clinical results and bone union.

Keywords: Cervical trauma; Axis body fracture; Classification

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1. Introduction

Cervical spine trauma accounts for 5% of all trauma patients, and among them, fractures of the axial spine are known to be the most common at 32% [1,2]. As the population ages, the number of patients diagnosed and treated for axial spine fractures is increasing, reaching 600 per year according to statistics [3,4]. Due to its anatomical specificity, the axial fractures appear in various forms such as odontoid fractures, hangman fractures, lateral body fractures, and vertebral body fractures, and the classification and treatment of fractures other than vertebral body have already been reported in several papers [5-8]. Fujimura and Benzel *et al.* proposed a morphologic classification of fractures for vertebral body fractures of the axial spine, but it has limitations when applied to various types of fractures seen in clinical practice [9,10]. Therefore, we aim to report the morphologic classification of vertebral body fractures of the axial spine, their frequency, and treatment outcomes using plain radiographs and three-dimensional computed tomography (3D CT).

2. Materials and methods

Among 107 patients diagnosed with vertebral body fractures from 2005 to 2019, we excluded 12 patients with hangman fractures and 10 patients with fractures outside the vertebral body, such as the posterior arch and spinous process. Of the 3 types of spinous process fractures, those involving more than 1/2 of the spinous process bilaterally were classified as vertebral body fractures, and those involving less than 1/2 were classified as spinous process fractures, and 32 patients were excluded. Among the 53 patients with vertebral body fractures, 9 patients with history of cervical spine surgery or showed no bone union after 6 months of treatment were excluded. At last, 44 patients were retrospectively analyzed.

Radiographs and 3D CT of the cervical spine were performed to analyze the appearance of the fracture line. The fracture lines were classified as coronal, sagittal, transverse, avulsion, and complex according to their morphology, and complex was defined as a combination of two or more different fracture lines. The mean age at presentation, gender ratio, mechanism of injury, intervertebral ligament injury, comorbidity, neurological symptoms, and clinical outcomes of each group were compared and analyzed.

The mechanism of injury was categorized into slip, fall, and traffic accident. Intervertebral ligament injuries were assessed based on magnetic resonance imaging, and fractures in other parts of the spine were considered as comorbidities. Neurologic symptoms included radiating pain, tingling, and placebo sensation that occurred immediately after the injury. All patients were initially treated conservatively with a neck brace if the fracture was stable, and a halo-vest if unstable. Stability of the fracture was determined by a combination of the degree of dislocation of the fracture fragment, the presence of intervertebral ligament damage, the presence of fractures in adjacent vertebrae, and the presence of neurologic symptoms. If fracture instability persisted despite conservative treatment or if there was no evidence of bone union for more than 6 months, surgical treatment was carried out. Clinical outcomes included the evaluation of persistence of neurologic symptoms, fracture union, and local infection at the pin insertion site. Fractures were considered united when there was no pain at the fracture site and radiographic and 3D CT findings demonstrated trabecular union in at least one cortical bone [11]

This study was approved by the Institutional Review Board (IRB No. 2020-09-064).

3. Results

The study subjects included 24 men and 20 women. The average age at the time of hospitalization was 61.7 years old (25–81 years old). The average follow-up period was 14.2 months (7–33 months). The mechanism of injury was slip and fall in 5 cases, fall from height in 13 cases, and motor vehicle accident in 26 cases. Intervertebral ligament injury was observed in 18 cases. In 25 cases, fractures were present in areas other than the axial spine. Neurological symptoms at the time of presentation included radiating pain and tingling in the upper extremities in 10 cases and mild to moderate muscle weakness in 3 cases, totaling up to 13 cases. Conservative treatment was performed using a neck brace in 16 cases and a halo-vest in 28 cases, and surgical treatment was performed in 2 cases that was treated with a halo-vest due to no evidence of union.

At final follow-up, neurologic symptoms had resolved in all but four cases of mild upper extremity tingling. Osteosynthesis was achieved in all cases, including the 2 cases that underwent surgical treatment, and 4 cases showed evidence of malunion but no complaints of discomfort. The mean duration of union was 7.7 months (5–19 months). Of the 28 cases treated with a halo-vest, localized infection at the pin insertion site occurred in 3 cases, but were all resolved with antibiotics, and there was no evidence of infection at final follow-up.

4. Fracture classification

Fractures can be classified into five categories according to the morphologic shape of the fracture line: coronal, sagittal, axial, diaphyseal, and combined. Coronal, axial, sagittal, and sagittal images from radiographs and 3D CTs taken at the time of presentation, as well as 3D reconstruction images, were considered.

4.1. Coronal type

The fracture line of coronal type fracture is at the vertebral body parallel to the coronal plane, in which five cases were included in this study. The fracture lines were mainly located in the posterior part of the vertebral body, starting from the area of the intervertebral transition between the spinous process and the spinal canal, extending to the inferior part of the vertebral body (**Figure 1**). It is thought that compressive and shear forces acted from the posterior superior to the anterior inferior in the extensor position. The patients were injured in two cases by falls and in three cases by automobile accidents. Two cases had concomitant intervertebral ligament injuries the other four had concomitant non-vertebral fractures. Conservative treatment included a neck brace in three cases and a halo-vest in two cases. As for neurological damage, two patients complained of right-hand numbness and mild placebo sensation at the time of presentation, but there were no symptoms at final follow-up.

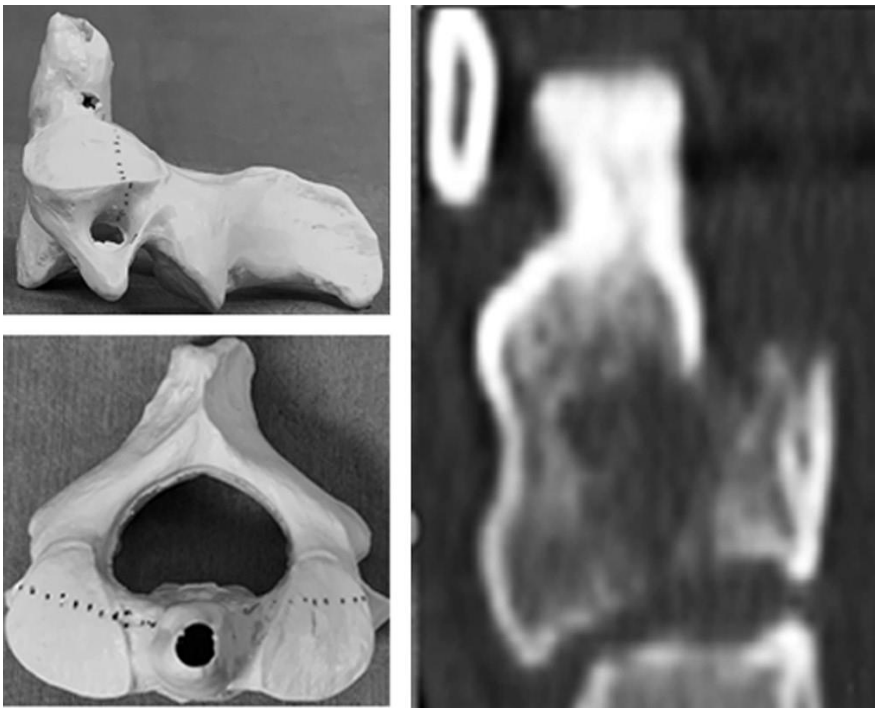

Figure 1. Coronal-type C2 vertebral body fracture depicted on an anatomical skeleton model and CT scan. The purple dotted line is the fracture line, located mainly in the posterior aspect of the vertebral body. It originates from the transitional zone of the odontoid process, moves to the vertebral body, which is connected to the spinal canal, and exits to the base of the C2 vertebral body (A-C).

4.2. Sagittal type

The fracture line of sagittal-type fracture is located at the vertebral body parallel to the sagittal plane, in which five cases were included in this study. The fracture line ran from the upper articular process to the transverse process or the lower articular process (**Figure 2**). The fracture line was unilateral and was thought to have been subjected to lateral pressure above flexion. The patients were all motor vehicle accident victims. Conservative treatment was performed with a neck brace in 3 cases and a halo-vest in 2 cases. Neurological injuries included mild placebo sensation in the unilateral hand in 1 case at presentation and mild tingling at the final follow-up.

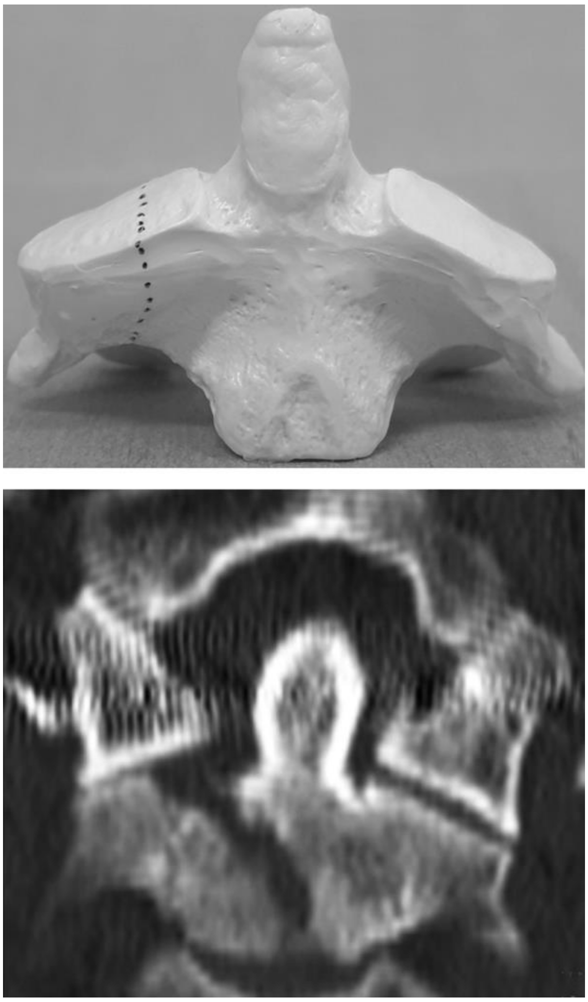

Figure 2. Sagittal-type C2 vertebral body fracture depicted on an anatomical skeleton model and CT scan. The purple dotted line is the fracture line, originating from the superior articular process and extending to the ipsilateral side of the transverse foramen or inferior articular process (A-B).

4.3. Transverse type

The fracture line of transverse-type fractures is located at the vertebral body parallel to the axial plane, in which eight cases were included in this study. The fracture line included the supra-articular process or started from the outer side of the spinous process and continued to the contralateral transverse process or vertebral body lateralization, and the upper fragment included the spinous process (**Figure 3**), which are most likely caused by compressive and rotational forces. In 2 cases, the injury was caused by a slip and fall, 1 case by a falling from a height, and 5 cases by a motor vehicle accident. 4 cases were accompanied by intervertebral ligament injuries, and 2 cases were accompanied by fractures other than axial vertebrae. Conservative treatment was performed with a neck brace in two cases and a halo-vest in six cases. In 1 case treated with a halo-vest, pain persisted and there was no evidence of fusion even after 6 months of treatment, so a 1-2 cervical interbody fusion was proposed using the posterior reach method, but the patient did not consent. Therefore, the patient was monitored, and surgical treatment was performed 1 year later. Due to neurological damage, 1 patient complained of right upper extremity pain and numbness at the time of presentation, 1 patient complained of mild placebo sensation, and 1 patient complained of mild numbness at the time of final follow-up. One case treated with a halo-vest had a localized infection that required additional antibiotics, and there was no evidence of infection at final follow-up.

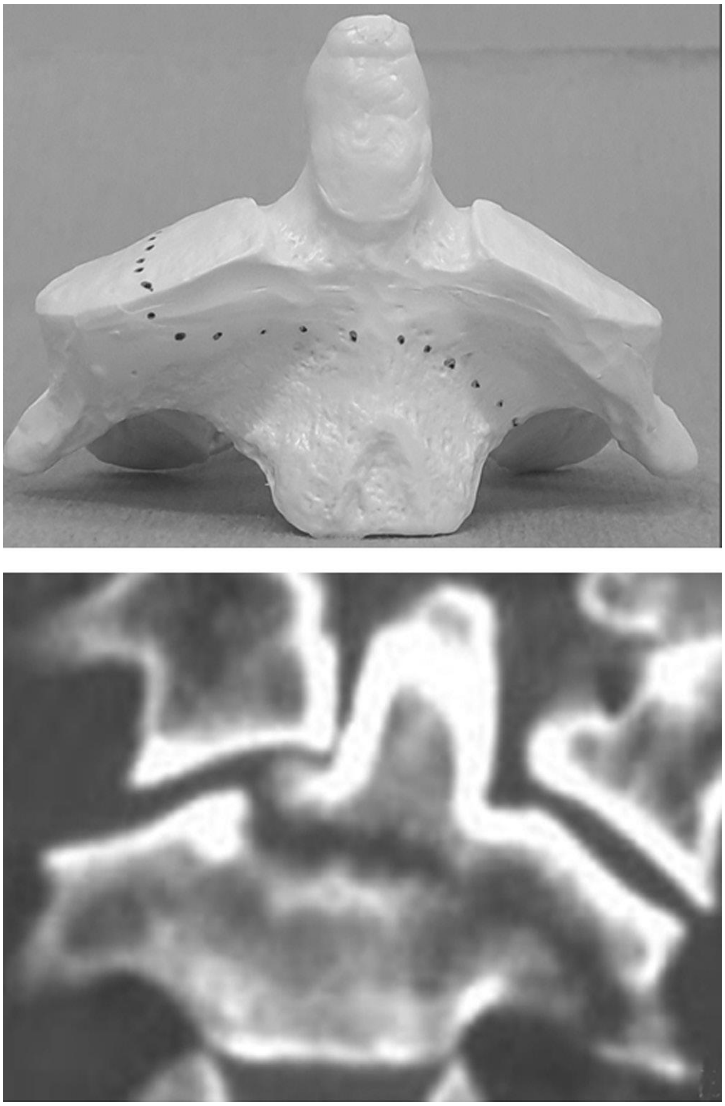

Figure 3. Transverse-type C2 vertebral body fracture depicted on an anatomical skeleton model and CT scan. The purple dotted line is the fracture line, originating from the medial side or the middle of the superior articular process and extending to the contralateral side of the vertebral body (A-B).

4.4. Avulsion type

The fracture line of avulsion-type fractures runs from the anterior superior to the posterior inferior of the vertebral body (**Figure 4**), in which seven cases were included in this study. The fractures were all fractures of the anterior longitudinal ligament and were thought to have been caused by extensor forces. The injury was caused by a slip and fall in 1 case, a fall from a height in 2 cases, and a motor vehicle accident in 4 cases. Two cases were accompanied with intervertebral ligament injuries, and five cases were accompanied with fractures other than the axial spine. Four cases were treated conservatively with a rigid brace and three cases with a Yoon vest brace. Neurologic injury included upper extremity numbness at presentation in 5 cases and mild numbness at final follow-up in 1 case. Malunion was noted in 1 case, but there was no discomfort at final follow-up.

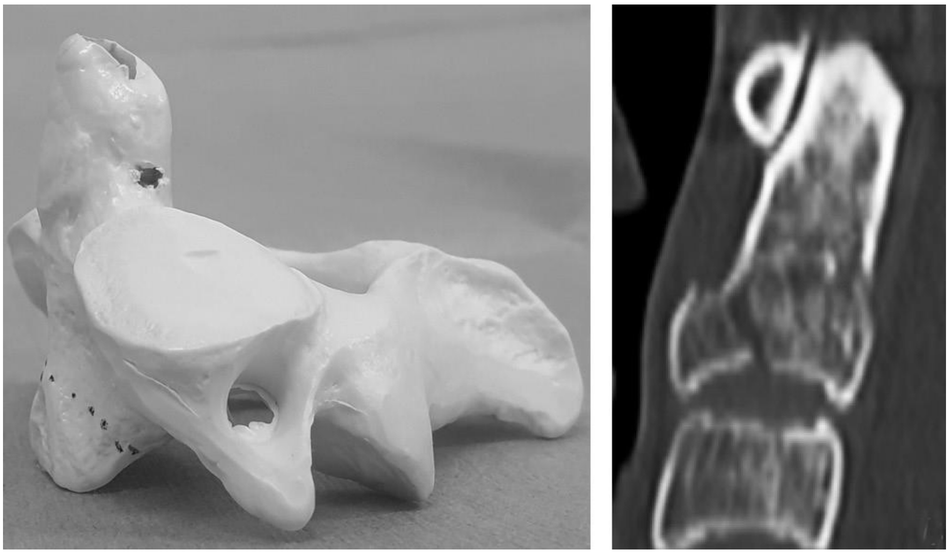

Figure 4. Avulsion-type C2 vertebral body fracture depicted on an anatomical skeleton model and CT scan. The purple dotted line is the fracture line, lying on the anterior-inferior side of the vertebral body, which corresponds to the insertion site of the anterior longitudinal ligament (A-B).

4.5. Complex type

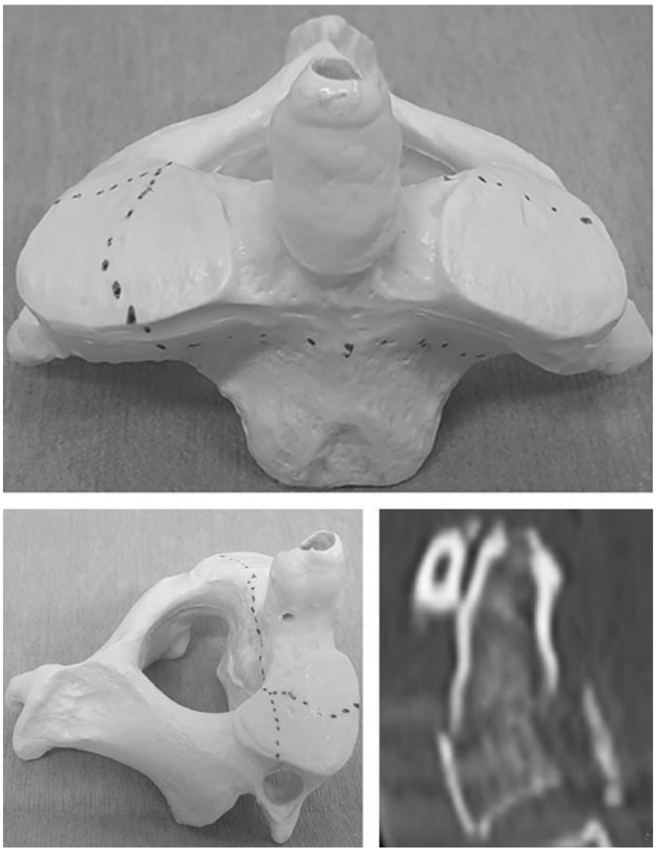

Figure 5. Complex-type C2 vertebral body fracture, corresponding to a combination of more than one fracture line, depicted on a CT scan and an anatomical skeleton model. The purple dotted line is the fracture line, which is a combination of coronal and transverse fracture lines (A-C).

This group consisted of cases involving two or more fracture lines in the vertebral body (**Figure 5**), in which 19 cases were included in this study. The injury was caused by a slip and fall in 2 cases, a fall from a height in 8 cases, and a traffic accident in 9 cases. Five cases involved intervertebral ligament injuries, and 9 cases involved fractures other than the axial spine. Conservative treatment was performed with a neck brace in 4 cases and a halo-vest in 15 cases. In 1 case, the patient was treated with the halo-vest, but the patient did not cooperate with the medical staff, and despite multiple adjustments, there was still instability of subluxation and subjugation and worsening pain. Seven weeks after the treatment, a 2-3-4 level cervical interbody fusion was performed using the posterior approach. Neurological damage: Upper or lower extremity numbness was present in 3 cases upon presentation, and mild upper extremity numbness was present in 1 case at final follow-up. Malunion occurred in 3 cases, but there were no complaints of discomfort at final follow-up. Of the 15 cases treated with the halo-vest, 2 cases showed localized infection at the pin insertion site, which required additional antibiotics, and no infection was found at final follow-up.

5. Case analysis

A 60-year-old female patient presents after falling from a height of 4 meters. She had a history of steroid use for rheumatoid arthritis, and on physical examination, she had a degloving injury on her face. Cervical spine radiographs showed fracture lines along the axial and sagittal planes of the vertebral bodies, with multiple rib fractures and orbital fractures as comorbidities (**Figure 6**). Interbody fusion of the 1st-2nd-3rd cervical vertebrae using the posterior approach could be considered for surgical treatment but considering the clinical outcome of the patient's comorbidities and limited postoperative range of motion, conservative treatment with a halo-vest was performed. Twelve weeks later, the osteosynthesis was and halo-vest were removed, and there was no evidence of osteosynthesis or instability on the final follow-up radiographs, and good clinical outcome (**Figure 7**).

Figure 6. A 60-year-old woman with a degloving injury on the forehead. (A) A lateral view of a plain radiograph of the cervical spine shows a complex fracture line. A coronal-type fracture line on the posterior aspect of the axis body and a transverse-type fracture line at the base of the odontoid process. (B) A sagittal image of a CT scan clearly demonstrates the radiographic findings. (C) The blue arrow indicates the fracture line.

Figure 7. Final follow-up of the same patient at post-traumatic 9 months. Plain radiography and computed tomography show formation of a callus and trabeculae across the fracture site (A-B). The flexion-extension view shows no evidence of instability (C).

6. Literature review

As the elderly population increases and diagnostic techniques become more common, fractures of the axial spine are on the rise [4]. Axial spine fractures are classified according to the anatomical location of the fracture line. The frequency, classification, treatment, and outcomes of odontoid fractures, hangman fractures, and lateral mass fractures have been reported in literature, but there are not many reports on vertebral body fractures [12].

In the United States, there are approximately 50,000 cases of cervical spine fractures per year, of which fractures of the axial spine are the most common, accounting for 32% [1,2]. The most common form of axial spine fracture is odontoid fracture, which is reported to be 58–75%, and the frequency of vertebral body fractures is reported to be about 10% of upper axial spine fractures. The proportion of vertebral body fractures varies widely, with Greene *et al.* reporting 67 of 340 vertebral body fractures (20%), Burke *et al.* reporting 31 of 165 (18%), Lomoschitz *et al.* reporting 7 of 90 (8%), and Bakhsh *et al.* reporting 11 of 26 (42%) [12-16]. The reason for this variation in reported rates of vertebral body fractures is likely due to the lack of a clear definition and confusion in distinguishing vertebral body fractures from vertebral body fracture type 3. Spinous process fracture type 3 is generally defined as a fracture involving the spinous process on the unilateral side and the fracture line involving the cancellous bone portion of the vertebral body, but the clinical presentation, treatment policy, and prognosis are different from types 1 and 2 [14]. There are various disagreements on the classification of spinous process fracture type 3 as a vertebral body fracture, and in this study, cases involving more than 1/2 of the bilateral gastrocnemius process were classified as vertebral body fractures, which were included; and cases involving less than 1/2 were classified as spinous process fractures, which were excluded (**Figure 8**) [2]. Atypical hangman fractures were excluded from vertebral body fractures in this study because the main anatomical location of the fracture is the isthmus of the axial spine [8,17].

German *et al.* reported the morphologic classification and treatment results of 21 patients with vertebral body fractures [18] and classified the fractures into two groups: vertical-coronal oriented and vertical-sagittal oriented. Benzel *et al.* reported fracture morphology, classification, and treatment results according to cervical spine posture and external force direction at the time of injury in 15 patients with vertebral body fractures and classified them into three groups: coronal, sagittal, and horizontal [9]. Fujimura *et al.* reported morphological classification and treatment results in 31 patients with vertebral body fractures, and classified them into four groups: avulsion, transverse, burst, and sagittal [10]. However, each study has limitations such as insufficient number of patients and inability to classify all types of vertebral body fractures seen in clinical practice. In this study, we analyzed the radiographic images of patients who visited our clinic and classified them into five morphological types: coronal, sagittal, transverse, avulsion, and combined.

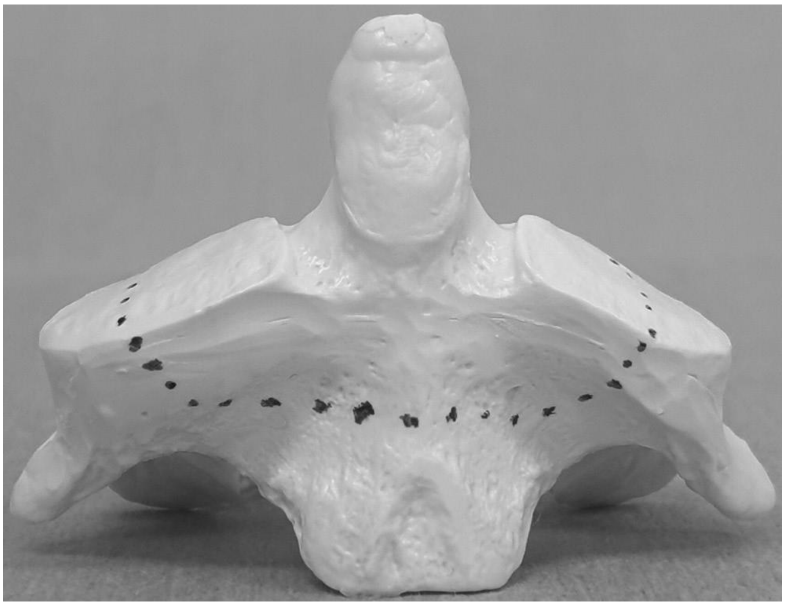

Figure 8. Example of a transverse-type C2 vertebral body fracture depicted on an anatomical skeleton model. The purple dotted line is the fracture line. It was classified as a transverse-type C2 vertebral body fracture because more than half of both superior articular processes was involed. It is difficult to distinguish from a type III dens fracture.

Some studies have shown good results with conservative treatment for vertebral body fractures [18–19]. In this study, conservative treatment was performed first, which is using a neck brace or halo-vest depending on the stability of the fracture. Although there was no statistical significance due to the small number of cases, the rate of treatment with the halo-vest was high in the transverse and complex types (75% in the transverse type and 79% in the complex type), as shown in **Table 1**. Conservative treatment resulted in bone union in 42 of 44 cases (95%) with good clinical outcomes at final follow-up, which was similar to previous studies. This may be due to the fact that the vertebral body of the axial spine is composed of cancellous bone, has a good blood supply, and a large cross-sectional area of the fracture.

A few articles have reported the outcomes of surgical treatment in vertebral body fractures. In a study of 28 patients, Zhang *et al.* performed conservative treatment when the fracture was stable and surgical treatment when there was adjacent joint instability or when the supraspinatus fracture fragment could not be treated [20]. Both groups reported good results in terms of osseointegration, but since cervical spine fusion causes movement restriction, surgical treatment should be decided with caution and the indications should be discussed further. In our institution, we performed surgical treatment in 1 case with no evidence of fusion despite conservative treatment and 1 case with persistent instability, which were transverse and complex types, respectively, and both cases achieved bone union at final follow-up.

Table 1. Demographics and complications of C2 vertebral body fracture

	Classification					
	Coronal	Sagittal	Transverse	Avulsion	Complex	Total
Number of cases	5	5	8	7	19	44
Demographics						
Male: Female	3 : 2	2 : 3	5 : 3	3 : 4	11 : 8	24 : 20
Age	64.0	48.4	64.0	61.6	63.7	61.7
Injury mechanism						
Slip down	0	0	2	1	2	6
Fall from height	2	0	1	2	8	12
Traffic accident	3	5	5	4	9	26
Discoligamentous injury	2	5	4	2	5	18
Combined injury	4	5	2	5	9	25
Neurologic symptom	2	1	2	5	3	13
Radiating pain & tingling sensation	1	0	1	5	3	10
Weakness	1	1	1	0	0	3
Treatment						
Neck collar	3	3	2	4	4	16
Halovest	2	2	5	3	14	26
Fusion	0	0	1	0	1	2
Complications						
Persistent neurologic symptoms	0	1	1	1	1	4
Mal-union	0	0	0	1	3	4
Pin site infection	0	0	1	0	2	3

This study is limited by the small number of cases. Other limitations include the difficulty in determining the exact direction of the external force at the time of injury. Although some biomechanical experiments have been conducted on the external forces acting on the vertebral body and fracture patterns, studies that consider the combined effects of fractures on anatomical structures such as ligaments and muscles around the vertebral body are lacking, and further research is needed [21].

7. Conclusion.

Vertebral body fractures of the axial spine accounted for approximately 50% of axial spine fractures. The fractures could be categorized into five types according to their morphology: coronal, sagittal, transverse, and complex. Conservative treatment resulted in bone union without significant complications and good clinical outcomes. We believe that conservative treatment can be used as a first-line treatment.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Passias PG, Poorman GW, Segreto FA, et al., 2018, Traumatic Fractures of the Cervical Spine: Analysis of Changes in Incidence, Cause, Concurrent Injuries, and Complications Among 488,262 Patients from 2005 to 2013. World Neurosurg, 110: e427–e37. https://www.doi.org/10.1016/j.wneu.2017.11.011

[2] Pryputniewicz DM, Hadley MN, 2010, Axis Fractures. Neurosurgery, 66(3 Suppl): 68–82. https://www.doi.org/10.1227/01.Neu.0000366118.21964.A8

[3] Hirschmann MT, Konala P, Amsler F, et al., 2011, The Position and Orientation of Total Knee Replacement Components: A Comparison of Conventional Radiographs, Transverse 2D-CT Slices and 3D-CT Reconstruction. J Bone Joint Surg Br, 93(5): 629–633. https://www.doi.org/10.1302/0301-620x.93b5.25893

[4] Pearson AM, Martin BI, Lindsey M, et al., 2016, C2 Vertebral Fractures in the Medicare Population: Incidence, Outcomes, and Costs. J Bone Joint Surg Am, 98(6): 449–456. https://www.doi.org/10.2106/JBJS.O.00468

[5] Seybold EA, Bayley JC, 1998, Functional Outcome of Surgically and Conservatively Managed Dens Fractures. Spine (Phila Pa 1976), 23(17): 1837–1845. https://www.doi.org/10.1097/00007632-199809010-00006

[6] Girardo M, Rava A, Gargiulo G, et al., 2018, Clinical and Radiological Union Rate Evaluation of Type 2 Odontoid Fractures: A Comparison Between Anterior Screw Fixation and Halo Vest in Elderly Patients. J Craniovertebr Junction Spine, 9(4): 254–259. https://www.doi.org/10.4103/jcvjs.JCVJS_93_18

[7] Murphy H, Schroeder GD, Shi WJ, et al., 2017, Management of Hangman's Fractures: A Systematic Review. J Orthop Trauma. 31(Suppl 4): S90–S95. https://www.doi.org/10.1097/BOT.0000000000000952

[8] Anderson LD, D'Alonzo RT, 1974, Fractures of the Odontoid Process of the Axis. J Bone Joint Surg Am. 56(8): 1663–1674.

[9] Benzel EC, Hart BL, Ball PA, et al., 1994, Fractures of the C-2vertebral body. J Neurosurg, 81(2): 206–212. https://www.doi.org/10.3171/jns.1994.81.2.0206

[10] Fujimura Y, Nishi Y, Kobayashi K, 1996, Classification and Treatment of Axis Body Fractures. J Orthop Trauma, 10(8): 536–540. https://www.doi.org/10.1097/00005131-199611000-00005

[11] Koller H, Acosta F, Forstner R, et al., 2009, C2-Fractures: Part II. A Morphometrical Analysis of Computerized Atlantoaxial Motion, Anatomical Alignment and Related Clinical Outcomes. Eur Spine J, 18(8): 1135–1153. https://www.doi.org/10.1007/s00586-009-0901-4

[12] Radovanovic I, Urquhart JC, Rasoulinejad P, et al., 2017, Patterns of C-2 Fracture in the Elderly: Comparison of Etiology, Treatment, and Mortality Among Specific Fracture Types. J Neurosurg Spine. 27(5): 494–500. https://www.doi.org/10.3171/2017.3.SPINE161176

[13] Bakhsh A, Alzahrani A, Aljuzair AH, et al., 2020, Fractures of C2 (Axis) Vertebra: Clinical Presentation and Management.Int J Spine Surg. 14(6): 908-15. https://www.doi.org/10.14444/7139

[14] Greene KA, Dickman CA, Marciano FF, et al., 1997, Acute Axis Fractures. Analysis of Management and Outcome in 340 Consecutive Cases. Spine (Phila Pa 1976), 22(16): 1843–1852. https://www.doi.org/10.1097/00007632-199708150-00009

[15] Kepler CK, Vaccaro AR, Fleischman AN, et al., 2017, Treatment of Axis Body Fractures: A Systematic Review. Clin Spine Surg. 30(10): 442–456. https://www.doi.org/10.1097/BSD.0000000000000309

[16] Lomoschitz FM, Blackmore CC, Mirza SK, et al., 2002, CervicalSpine Injuries in Patients 65 Years

Old and Older. AJR Am J Roentgenol. 178(3): 573–577. https://www.doi.org/10.2214/ajr.178.3.1780573

[17] Burke JT, Harris JH Jr, 1989, Acute Injuries of the Axis Vertebra. Skeletal Radiol, 18(5): 335–346. https://www.doi.org/10.1007/bf00361422

[18] German JW, Hart BL, Benzel EC, 2005, Nonoperative management of vertical C2 body fractures. Neurosurgery, 56(3): 516–521. https://www.doi.org/10.1227/01.neu.0000153908.53579.e4

[19] Motiei-Langroudi R, Sadeghian H, 2016, C2 Body Fracture: Report of Cases Managed Conservatively by Philadelphia Collar. Asian Spine J, 10(5): 920–924. https://www.doi.org/10.4184/asj.2016.10.5.920

[20] Zhang YS, Zhang JX, Yang QG, et al., 2014, Surgical Management of the Fractures of Axis Body: Indications and Surgical Strategy. Eur Spine J, 23(8): 1633–1640. https://www.doi.org/10.1007/s00586-013-3158-x

[21] Teo EC, Paul JP, Evans JH, et al., 2001, Experimental Investigation of Failure Load and Fracture Patterns of C2 (Axis). J Biomech, 34(8): 1005–1010. https://www.doi.org/10.1016/s0021-9290(01)00071-9

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