Fracture and contralateral dislocation of the twin facet joints of the lower cervical spine

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Abstract

Purpose The combination of a facet fracture and a contralateral facet dislocation at the same intervertebral level of the cervical spine (a fracture and contralateral dislocation of the twin facet joints) has not been described in detail. The aims of this study are to report a series of 11 patients with this injury, to clarify the clinical features and to discuss its pathomechanism.

Methods Among 251 patients with lower cervical spine fractures and/or dislocations surgically treated, 11 (9 males and 2 females, averaged age, 52 years) had this kind of injury. Medical charts and medical images were reviewed retrospectively.

Results Injury levels were C4-5, C5-6 and C6-7 in 1, 4 and 6 patients, respectively. A fracture was found at the superior facet in 6, and at the inferior facet in 5. The anterior displacement of the vertebral body ranged from 7 to 19 mm. The unilateral horizontal facet appearance on an

anteroposterior radiograph and the triple image on a CT composed of a separated fracture fragment, the base of the fractured facet, and the neighboring non-fractured facet were characteristic. All patients had neurological deficits from Frankel A to D, and were surgically treated by posterior fusion using wire or cable, or combined anterior and posterior spinal fusion.

Conclusions The fracture and contralateral dislocation of the twin facet joints can cause severe neurological deficits because of its gross anterior displacement. Its plausible pathomechanism is extension force exerted to the cervical spine when it is maximally bent laterally.

Keywords Cervical spine · Facet fracture · Facet dislocation · Distractive flexion injury · Compressive extension injury · Neurological deficits

Introduction

Several classification systems of lower cervical spine injury have been described but none has demonstrated superior reliability or validity [1, 4, 12, 14, 16, 17, 26]. The comprehensive classification proposed by Allen et al. is based on the mechanism of injury such as the compression flexion and vertical compression phylogenies and has been commonly used [1, 12]. Recently, the AO classification system and the Sub-axial Injury Classification (SLIC) system have been developed [14, 16, 17]. Simpler classification systems should be better for understanding and easier for daily use. Classification system should aim to be both simple and covered all types of pathology. However, there have been no classifications that can be completely compatible with these two purposes. Every system has exceptional cases that cannot be classified well.

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Here, we report 11 patients with the combination of a fracture of the superior or inferior facet on one side and a dislocation of the facet joint on the other side at the same intervertebral level of the lower cervical spine. This injury has not been described in detail and might not be classified by the classification systems ever reported and therefore, might not been paid attention by spine surgeons in the world. But it demonstrates a gross anterior displacement of the vertebral body and often causes severe spinal cord injury. We designated such an injury as a “fracture and contralateral dislocation of the twin facet joints”. The aims of the present study are to clarify the clinical features of this type of injury, and to discuss the injury mechanism.

Materials and methods

We retrospectively reviewed 251 patients with subaxial cervical spine injuries surgically treated at the Department of Orthopaedic Surgery, Tohoku University School of Medicine and its affiliated orthopaedic departments in the Miyagi Prefecture and surrounding areas in northeastern Japan. They were 195 males and 56 females and their age at surgery ranged from 15 to 87 years (average, 47 years). The injury phylogenies of those 251 patients according to the Allen’s classification were summarized in Table 1 and their morphologies according to the SLIC system in Table 2 [1, 17]. There were 70 patients with bilateral facet dislocation, 15 with a unilateral facet dislocation, 35 with a unilateral superior facet fracture, 30 with a unilateral inferior facet fracture, and 9 with a unilateral pillar fracture [9, 25], i.e., a combined pedicle and laminar fracture causing separation of the articular pillar [10]. In addition, among 37 patients who could not be applied to any phylogenies in this classification. Two types of phylogenetic combinations might result in them: a combination of compressive flexion and vertical compression injuries, i.e., a teardrop fracture and split vertebral fractures, in 26

Table 1 Injury phylogenies of 251 patients according to the Allen’s classification

Phylogeny	Nm. of cases (%)
Compressive flexion	14 (5.6)
Vertical compression	15 (6.0)
Distractive flexion	85 (33.9)
Compressive extension	82 (32.7)
Distractive extension	14 (5.6)
Lateral flexion	4 (1.6)
Others	37 (14.7)
Total	251 (100)

Table 2 Injury morphologies of 251 patients according to the Subaxial Injury Classification (SLIC) system

Morphology	No. of cases (%)
No abnormality	0 (0)
Compression	18 (7.2)
Burst	11 (4.4)
Distraction	122 (48.6)
Rotation/translation	100 (39.8)
Total	251 (100)

patients, and a fracture and dislocation of the twin facet joints in 11 patients. The latter 11 patients are the subjects of this study. Medical and operative charts were retrospectively reviewed to determine the causes of injuries, to determine whether the patients had spinal cord injuries, and to determine the undertaken surgical procedures. The severity of the spinal cord injuries was assessed using the Frankel’s rating system [8].

All of the 11 patients had conventional plain radiographs taken with a tube-to-film distance of 1.8 m. The radiographs were reviewed focusing on the following findings: forward/backward bend or separation of the superior or inferior facet, horizontal facet appearance on an anteroposterior radiograph as signs of the facet fracture [7], facet dislocation, displacement of the superjacent vertebral body to the injury level where the facet fracture and the facet dislocation were concurrently found, anteroposterior diameter of the spinal canal, and any accompanying fractures or dislocations. The postoperative radiographs were also confirmed. All the patients had CT scans. The CT scans were reviewed focusing on sides of the facet fracture and the facet dislocation, direction of the displacement of the superjacent vertebral body to the injury level, and “triple image” of the fractured facet joint composed of a separated fracture fragment, the intact counterpart and the base of the fractured facet [3]. The MR images were obtained from 10 patients and were reviewed to evaluate spinal cord compression.

All patients were informed that their data would be submitted for publication, and they gave us their consent.

Results

The patients included 9 males and 2 females. Their ages ranged from 31 to 71 years (average, 52 years). The causes of injuries were traffic accidents in 6 patients (automobile in all), falls from a height in 4, and a work-related accident in 1. All patients had spinal cord injuries: 8 had Frankel A, 1 had Frankel C, and 2 had Frankel D paralyse (Table 3) [8].

Table 3 Neurological deficits of the 11 cases evaluated using the Frankel's rating system [8]

	Frankel A	Frankel B	Frankel C	Frankel D	Frankel E	Total
Superior facet fracture + contralateral facet dislocation	5	0	1	0	0	6
Inferior facet fracture + contralateral facet dislocation	3	0	0	2	0	5
Total	8		1	2		11

The injury levels were C4-5 in 1 patient, C5-6 in 4 and C6-7 in 6. A right facet fracture and a left facet dislocation were found in 8 patients. A left facet fracture and a right facet dislocation were found in the remaining 3 patients. The fractured facets were the superior facet in 6 patients and the inferior facet in 5 (Figs. 1, 2, 3, 4). They all demonstrated either forward or backward bend or separation of the fractured facets from their bases on a lateral or oblique radiograph or both. A horizontal facet was seen in 8 patients on an anteroposterior radiograph: at the superior

facet in 6 and at the inferior facet in 2 (Fig. 1a) [7]. An avulsion fracture of the anterosuperior corner of the vertebral body subjacent to the injury level was found at C6 in 1 patient and at C7 in 3 (Fig. 3b). The combined injuries in the cervical spine were found in 3 patients: pedicle or laminar fracture at one cranial level in 1 each and the spinous process fracture of the same level in 1.

Anterior displacement of the suprajacent vertebral body to the injury level was found in all 11 patients (Figs. 1b, 2a, 3a, 4a). It measured from 7 to 13 mm (average, 10 mm) and the percentage displacement ranged from 35 to 75% (average, 45%) of the anteroposterior width of the upper endplate of the subjacent vertebral body in the group of superior facet fracture. It measured from 7 to 19 mm (average, 11 mm) and the percentage displacement ranged from 50 to 80% (average, 60%) in the group of inferior facet fracture. The anteroposterior diameter of the spinal canal of the subjacent vertebra to the injury level ranged from 14 to 20 mm (average, 17 mm). The space available for the spinal cord (SAC), that was calculated as an anteroposterior diameter of the spinal canal subtracted by a distance of anterior displacement of the subjacent vertebral body, ranged from 5 to 9 mm (average, 7 mm).

On CT scans, little or no rotational displacement was demonstrated in all patients. The “triple image” composed of a fragment of facet fracture, the base of the fractured facet, and the adjacent facet in between was demonstrated in 9 patients (Figs. 1c, 3b, 4b) [3]. In the other 2 patients, the fracture fragment was still connected with the base of the fractured facet (Fig. 2b).

Out of the 10 patients examined by MR images, compression of the spinal cord by the intervertebral disc herniation from anterior and by the suprajacent lamina from posterior at the injury level was shown in 6 patients. The remaining 4 patients had compression of the spinal cord by the posterosuperior corner of the vertebra and the suprajacent lamina.

Reduction was relatively easily achieved in all patients: the dislocated vertebra was reduced by preoperative Halo traction in 3 patients. In the others, gentle reduction with neck extension was performed under general anesthesia and when the dislocated facet joint was not reduced by this procedure, the facet was excised. Subsequently, posterior spinal fusion with bone graft was performed by

Fig. 1 A 65-year-old male with Frankel A spinal cord injury. Injured by fall down from a step at 2 m height. **a** Anteroposterior radiograph. A fracture of the right superior facet of the C6 vertebra resulting in the “horizontal facet” appearance (arrowhead). **b** Lateral radiograph. A forward bent fragment (arrowhead) of the fractured superior facet of the C6 vertebra and a contralateral facet dislocation (arrow). There is gross anterior displacement of C5 on C6. Note an avulsion fracture of anterosuperior corner of the subjacent vertebral body (shorter arrow). **c** CT scan. A fracture of the right superior facet of the C6 vertebra confirmed by the “triple image” composed of a fragment (a) and the base of the fractured superior facet (b), and the inferior facet above in between (c) and a dislocation of the left inferior facet (arrow) of the C5 vertebra. **d** Postoperative lateral radiograph. Posterior spinal fusion with bone graft was performed using interlaminar wiring from C5 to C6 and anterior displacement of C5 is well-reduced on C6

Fig. 2 A 42-year-old male with Frankel A spinal cord injury. Injured by traffic accident. **a** Lateral radiograph. A fragment of the fractured inferior facet (*arrowhead*) and a dislocation of the other inferior facet (*arrow*) of the C4 vertebra. Note a gross anterior displacement of the vertebral body of C4 on C5. **b** CT scan. Fracture fragments of the left

inferior facet (*arrowheads*) and a dislocation of the right inferior facet (*arrow*) of the C4 vertebra are detected. **c** Postoperative lateral radiograph. Combined anterior spinal fusion with iliac bone graft at C4/5 and posterior spinal fusion using interlaminar cables from C3 to C5 was performed

Fig. 3 A 33-year-old male with Frankel D spinal cord injury. Injured by traffic accident. **a** Lateral radiograph. C7 vertebral body demonstrates an avulsion fracture (*shorter arrow*). There is an anterior displacement of C6 on C7. **b** CT scans. The “triple image” including a fractured right inferior facet and a fragment (*arrowheads*) is demonstrated and the left inferior facet is dislocated (*arrow*). **c** Postoperative lateral radiograph. Posterior spinal fusion of C6/7 using interlaminar wire was performed. The C6 vertebral body is well-reduced and C6/7 facet fusion is completed

interlaminar wiring described by Rogers in 4 or by sublamina wiring described by Watts et al in 1 (Fig. 1d, 3c) [19, 28]. Combined anterior spinal fusion with posterior fusion using interlaminar wiring was performed in 6 patients (Fig. 2c). Intraoperatively, ligamentous injuries were detected in five patients, which were in anterior longitudinal ligament, posterior longitudinal ligament, ligamentum flavum, and supra- or inter spinous ligament. Dural

Fig. 4 A 49-year-old female with Frankel A spinal cord injury. Injured by traffic accident. **a** Lateral radiograph. C6 vertebral body demonstrates an anterior displacement on C7. **b** CT scan. The “triple image” including a fractured right C7 superior facet and a fragment (*arrowheads*), a fractured C6 lamina (*arrow*) and a dislocated left C6 inferior facet (*shorter arrows*) are demonstrated

tear accompanied with the injury was also found in one patient.

Discussion

In 1982, Allen et al. proposed a classification for lower cervical spine injuries according to 6 common phylogenies with further divisions into stages [1]. It has contributed to understanding the mechanisms of injuries for the proper diagnosis and treatment. This classification has been commonly used [12], particularly in Japan. However, using the Allen’s classification system, injury patterns might not have understood exactly as we use CT scans or MR images since it was based on the findings obtained from classical plain radiographs. There have been several injury patterns that cannot be classified by the Allen’s classification [1]. For example, the combination of a teardrop fracture and a vertical split fracture, which has been described in numerous papers and was included more than 10% in our

series, cannot be classified by this classification [1, 13, 21, 23]. It should be classified as an interphylogenetic injury.

In 1994, the Orthopaedic Trauma Association has applied more comprehensive classification of thoracic and lumbar injuries to lower cervical spine injuries [14, 16]. In this system, the injuries are indicated by *the locations* (cervical; 51-, thoracic; 52-, lumbar; 53-), *the types* (fundamental injury pattern, A: compression injuries, B: distraction injuries, C: multidirection injuries with translation), *the groups* (morphological criteria such as impaction fracture and burst fracture), and *the subgroups* (more detailed morphological criteria such as burst-split fracture and transverse bicolonn fracture), and represented by Arabic numbers such as 51-A3.1. The Spine Trauma Study Group has introduced another classification in 2008, named as the SLIC system and Severity Scale [18]. This classification is composed of 3 major injury characteristics: injury morphology, integrity of the disco-ligamentous complex and neurological status of the patients. The AO classification and SLIC system might provide more accurate description of injuries.

The fracture and contralateral dislocation of the twin facet joints might classified into 51-B2.3, posterior disruption predominantly osseous associated with vertebral body compression fracture by the AO classification or translation injury by the SLIC system [14, 16, 17]. But the 51-B2.3 injury is not detailed in the literature and “translation injury” might be rough involving many kinds of fracture/dislocations. There have been no reports described on the characteristics of this injury with systematical analysis.

In our literature review, we may come across only a case having the fracture and contralateral dislocation of the twin facet joints in tables in the paper by Allen et al., which accounted for 0.6% of their series of lower cervical spine injuries [1]. Regrettably, the authors did not comment on this case in the text of their paper. This combination of fracture and dislocation was found in 4.4% in our series. Our higher incidence is most likely due to the better diagnosis afforded by the routine usage of CT scans for analysis. The fracture and contralateral dislocation of the twin facet joints, therefore, should not be rare.

Unilateral facet fracture-dislocations of the lower cervical spine cause a rotatory displacement of the suprajacent vertebral body to the injury level, thereby presenting the following radiological appearances [3, 5]: (1) double contour sign of the twin facets on the lateral radiograph [5], (2) deviation of the spinous process on the anteroposterior radiograph, (3) displacement of the vertebral body on an oblique radiograph and step-like disruption of alignment of the pedicles on the opposite oblique radiograph [15]. However, none of these findings was found in all 11 cases

having the fracture and contralateral dislocation of the twin facet joints in this study. Most cases demonstrated the unilateral horizontal facet appearance on an anteroposterior radiograph and the triple image of a facet joint on CT scan with no rotatory displacement [3, 7]. Thus, this combined fracture and dislocation can be differentiated from unilateral facet fracture-dislocations by plain radiographs and CT scan.

Unilateral facet fracture-dislocations of the lower cervical spine cause a mild or moderate anterior displacement of the vertebral body superjacent to the injury level, averaged 4 mm in unilateral facet dislocations while 3 mm in unilateral facet fractures, or averaged 14% in unilateral superior facet fractures whereas 29% in unilateral inferior facet fractures, as the contralateral facet joint is intact [2, 24]. Thus, they might be missed in the polytrauma cases at initial evaluation. On the other hand, in the fracture and contralateral dislocation of the twin facet joints, the anterior displacement was greater and resulted in a narrow SAC averaging 7 mm. Major anterior displacement should be characteristic feature of this injury.

The complication rates of cervical spinal cord injuries have been reported as from 12 to 70% in unilateral facet dislocations and 0 to 27% in unilateral facet fractures [1, 2, 5, 15, 18, 20, 24]. In contrast, all of the 11 patients with the fracture and contralateral dislocation of the twin facet joints in our series had spinal cord injuries, which were graded Frankel A in 8 patients [8]. The main causative factors of their spinal cord injuries were the reduced SAC by the anterior displacement of the vertebral body and accompanying disc herniation, which resulted in the significant narrowing of the spinal canal.

It is widely accepted that unilateral facet dislocations of the lower cervical spine are produced by rotational distractive flexion [1–3, 5, 6], while unilateral fractures of the vertebral arch, either the superior or inferior facet, or the pedicle and lamina, are produced by rotational compressive extension force exerted in a position of ipsilateral side bending and/or contralateral rotation [1, 9, 11, 22, 25]. Theoretically, a plausible mechanism of the fracture and contralateral facet dislocation of the twin facet joints is extension force exerting to the lower cervical spine in a maximal lateral bent position (Fig. 5). This makes compressive extension force to the concave side, which might cause a unilateral facet fracture. On the other hand, more distraction force exerts to the opened facet joint by side bending in the convex side. The inferior articular process might get over the superior articular process. Then, anterior translational force may generate anterior displacement of the suprajacent vertebral body. Because the range of motion in extension at C4/5, 5/6 and 6/7 shows larger than that at C3/4 and C7/T1 [27], this injury might occur more often at these levels.

Fig. 5 A scheme showing the plausible mechanism of the fracture and contralateral facet dislocation of the twin facet joints. In the left side bending position, when extension force exerts to the lower cervical spine, the left superior facet may be fractured by the compression force while the right facet joint may be dislocated by the distraction force

The principle of the treatment of spinal fracture-dislocation is gentle reduction and rigid immobilization. In the fracture and contralateral dislocation of the twin facet joints in our series, reduction was relatively easily achieved. Then posterior spinal fusion or combined anterior and posterior fusion with interlaminar or sublaminar wiring was performed basically at single spinal level [19, 28]. To obtain a higher primary stability, rigid instrumented fixation such as pedicle screw and rod system should be better [4, 11], especially for early rehabilitation in plegic patients.

In conclusion, the fracture and contralateral dislocation of the twin facet joints is not rare. Because of the major anterior displacement, this injury causes severe neurological deficits. This injury shows characteristic findings radiologically; the unilateral horizontal facet appearance on an anteroposterior radiograph and the triple image of a facet joint on a CT scan. We should investigate the radiographs and CT scans of the patients with lower cervical spine injury carefully and should not miss this condition. Gentle reduction and subsequent posterior spinal fusion or combined anterior and posterior spinal fusion, depends on the destruction of the vertebral body, should be recommended for patients with the fracture and contralateral dislocation of the twin facet joints.

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References

- Allen BL Jr, Ferguson RL, Lehmann TR, O'Brien RP (1982) A mechanistic classification of closed, indirect fractures and dislocations of the lower cervical spine. *Spine* 7:1–27
- Argenson C, Lovet J, Sanouiller JL (1988) Traumatic rotatory displacement of the lower cervical spine. *Spine* 13:767–773
- Argenson C, de Peretti F, Ghabris A, Eude P, Hovorka I (2000) Traumatic rotatory displacement of the lower cervical spine. *Bull Hosp Jt Dis* 59:52–60
- Aebi M, Mohler J, Zach GA, Morscher E (1986) Indication, surgical technique, and results of 100 surgically treated fractures and fracture-dislocations of the cervical spine. *Clin Orthop* 203:244–257
- Braakman R, Vinken PJ (1967) Unilateral facet interlocking in the lower cervical spine. *J Bone Joint Surg Br* 49:249–257
- Crawford NR, Duggal N, Chamberlain RH, Park SC, Sonntag VKH, Dickman CA (2002) Unilateral cervical facet dislocation: Injury mechanism and biomechanical consequences. *Spine* 27:1858–1864
- Forsyth HF (1964) Extension injuries of the cervical spine. *J Bone Joint Surg Am* 46:1792–1797
- Frankel HL, Hancock DO, Hyslop G, Melzak J, Michaelis LS, Ungar GH et al (1969) The value of postural reduction in the management of closed injuries of the spine with paraplegia and tetraplegia. *Paraplegia* 7:179–192
- Harris JH, Edeiken-Monroe B, Kopaniky DR (1986) A practical classification of acute cervical spine injuries. *Orthop Clin North Am* 17:15–30
- Judet R, Judet J, Roy-Camille R, Zerah J-C (1970) Saillant G (1970) Fractures du rachis cervical: fracture-séparation du massif articulaire. *Rev Chir Orthop* 56:155–164
- Kotani Y, Abumi K, Ito M, Minami A (2005) Cervical spine injuries associated with lateral mass and facet joint fractures: new classification and surgical treatment with pedicle screw fixation. *Eur Spine J* 14:69–77
- Kwon BK, Vaccaro AR, Grauer JN, Fisher CG, Dvorak MF (2006) Subaxial cervical spine trauma. *J Am Acad Orthop Surg* 14:78–89
- Lee C, Kim KS, Roger LF (1982) Triangular cervical vertebral body fractures: diagnostic significance. *Am J Roentgenol* 138:1123–1132
- Magerl F, Aebi M, Gertzbein SD, Harms J, Nazarian S (1994) A comprehensive classification of thoracic and lumbar injuries. *Euro Spine J* 3:184–201
- Nieminen R (1974) Fractures of the articular processes of the lower cervical spine: an analysis of 28 cases treated conservatively. *Ann Chir Gynaecol Fenn* 63:204–211
- Orthopaedic Trauma Association. Fracture and dislocation compendium (1996) *J Orthop Trauma* 10 (Suppl 1):1–154
- Patel AA, Dalley A, Brodke DS, Daubs M, Anderson PA, Hurlbert RJ, Vaccaro AR, Spine Trauma Study Group (2008) Subaxial cervical spine trauma classification: the Subaxial Injury Classification system and case examples. *Neurosurg Focus* 25:E8
- Rabb CH, Lopez J, Beauchamp K, Witt P, Bolles G, Dwyer A (2007) Unilateral cervical facet fractures with subluxation: injury patterns and treatment. *J Spinal Disord Tech* 20:416–422
- Rogers WA (1942) Treatment of fracture-dislocation of the cervical spine. *J Bone Joint Surg* 24:245–258
- Rorabeck CH, Rock MG, Hawkins RJ, Bourne RB (1987) Unilateral facet dislocation of the cervical spine: an analysis of the results of treatment in 26 patients. *Spine* 12:23–27
- Signoret F, Jacquot F, Feron JM (1999) Reducing the cervical flexion teardrop fracture with a posterior approach and plating technique. An original method. *Eur Spine J* 8:110–117

22. Shanmuganathan K, Mirvis SE, Levine AM (1994) Rotational injury of cervical facets: CT analysis of fracture patterns with implications for management and outcome. *Am J Roentgenol* 163:1165–1169
23. Torg JS, Pavlov H, O'Neill MJ, Nichols CE, Sennett B (1991) The axial load teardrop fracture. A biomechanical, clinical, and roentgenographic analysis. *Am J Sport Med* 19:355–364
24. Tani S, Ishii Y, Kokubun S (1994) Clinical feature and treatment of compressive extension injuries of the lower cervical spine. *Seikeigeka (Orthop Surg)* 45:533–540 (in Japanese)
25. Weir DC (1975) Roentgenographic signs of cervical injury. *Clin Orthop* 109:9–17
26. Whitley JF, Forsyth FH (1960) The classification of the cervical spine injuries. *Am J Roentgenol* 83:633–644
27. White A, Panjabi M (1990) Kinetics of the spine. In: *Clinical Biomechanics of the Spine*, 2nd edn. JB Lippincott, Philadelphia, pp 85–126
28. Watts C, Smith H, Knoller N (1993) Risks and cost-effectiveness of sublamina wiring in posterior fusion of cervical spine trauma. *Surg Neurol* 40:457–460