Teardrop Fracture of the Axis: An Evaluation of Vertebral Instability and Individualized Treatment

Xin Xin

Ankang City Central Hospital

Chen Yue

Ankang City Central Hospital

Guoqing Li

Ankang City Central Hospital

Xinxin Liu (✉ liuxinxin@163.com)

Xi'an Honghui Hospital

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instability and individualized treatment

Xin Xin¹, Chen Yue¹, Guoqing Li¹, Xinxin Liu^{2*}

Xin Xin, ¹Department of orthopaedics, Ankang Center Hospital, Ankang 725000,
Shaanxi province, P.R. China, E-mail: xcfxcy1981@163.com

Chen Yue, ¹Department of orthopaedics, Ankang Center Hospital, Ankang 725000,
Shaanxi province, P.R. China, E-mail: 1044584908@qq.com

Guoqing Li, ¹Department of orthopaedics, Ankang Center Hospital, Ankang 725000,
Shaanxi province, P.R. China, E-mail: 13991516126@139.com

Xinxin Liu, ²Department of Magnetic Resonance Imaging, Hong Hui Hospital of
Xi'an Jiaotong University, Xi'an 710054, Shaanxi province, P.R. China, E-mail:
liuxinxinfly2008@163.com

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*Correspondence to:

Xinxin Liu

Xi'an Jiaotong University

Department of Imaging

Hong Hui Hospital

Xi'an Jiaotong University College of Medicine

Xi'an, Shaanxi, China

Tel: 086-15009205693

E-mail: liuxinxinfly2008@163.com

Teardrop fracture of the axis: an evaluation of vertebral instability and individualized treatment

Background: Teardrop fractures of the axis (TDFAs) are avulsion fractures of the anterior-inferior part of the axis. Whether conservative or surgical treatment is better for TDFAs is controversial. Previously, image-based evaluations of the fractures have mainly focused on the teardrop fragment, the intervertebral disc and the prevertebral soft tissue. The treatment plan depends on the doctor's evaluation of fracture stability based on personal experience.

Methods: From January 2012 to December 2018, a total of 12 patients with TDFA were included in this prospective study. The stability of the TDFA vertebral body was evaluated by lateral X-ray measurements. Based on the evaluation of vertebral body stability, as well as the disease characteristics of the patients, individualized treatment schemes were adopted.

Results: Through the classification and treatment process, 6 patients with absolute instability and 6 patients with relative instability were identified. A total of 8 patients underwent surgery, and 4 patients were treated conservatively. A total of 12 patients finally achieved osseous fusion.

Conclusion: The treatment for TDFA should be determined by considering both the instability of the axial vertebra and the disease characteristics of the patient. With an appropriate classification and treatment process, both surgery and conservative treatment can yield good clinical outcomes.

Keywords: axis fracture, teardrop fracture, traumatic cervical instability, radiographic measurements, spinal fusion, internal fixation

Background

Kahn and Schneider first described teardrop fractures in 1956, characterized by a

1 triangular fragment at the anterior-inferior corner of the vertebral body [1]. TDFA is
2 different from teardrop fracture of the lower cervical spine in many respects and is
3 often regarded as a special entity, accounting for 12.7-15.6% of fractures of the axis
4 [2-4]. Common treatments for TDFA include the use of a cervical collar, Halo-vest
5 external fixation, anterior reduction, interbody fusion and internal fixation, or
6 posterior pedicle screw fixation and fusion [3-8,10,34]. It is very important to
7 evaluate fracture stability when determining whether to administer conservative or
8 surgical treatment. Previous investigations of fracture stability have focused on the
9 teardrop fragment, intervertebral disc and prevertebral soft tissue (PVST). The
10 treatment plan is based on the personal experience of the physician.

11 In this study, prospective treatment was used; lateral X-rays of the cervical spine
12 were used to measure the displacement and angulation of the vertebral body of the
13 axis and evaluate the traumatic instability of the axis. Based on the evaluation of the
14 stability of the vertebral body, as well as the disease characteristics of the patients,
15 individualized TDFA treatments were administered in this study.

17 **Materials and methods**

18 **Patient population**

19 This study was approved by the hospital institutional review board. Each subject
20 provided written informed consent. Twelve patients with TDFA from 2012-01 to
21 2018-12 at two academic institutions with available lateral X-ray images were
22 included in this study. In addition, individuals were excluded from the current study if
23 they had a history of prior upper cervical spinal fusion or fracture.

24 **Definitions and measurement of the relevant angles and displacement**

25 In 2007, the Spine Trauma Study Group [31] standardized the measurement of
26 the C2-3 angulation and displacement. All measurements were performed using
27 Viewer image analysis software. The software allows image magnification and direct
28 angular and linear measurements to be performed digitally (Fig. 1a, b). The angles
29 and displacement were calculated from the measurements for each patient.

Evaluation of disc injury

In the study, the methods presented by Watanabe [3] and Hu [4] were used to evaluate the severity of the TDFA disc injury, and Sander's [14] disc injury evaluation method was also considered. Injuries with high signal intensities and heterogeneous signals (hypointensity with perifocal hyperintensity) on the T2-weighted MRI scans were identified as severe intervertebral injuries.

Definition of absolute instability and relative instability in TDFA

Absolute instability was defined as the presence of (1) vertebral body displacement (> 3.5 mm) or/and angulation ($> 11^\circ$) or (2) severe disc injury. Relative instability was defined as (1) the presence of displacement < 3.5 mm and an angle $< 11^\circ$ and (2) the absence of severe disc damage.

Results

Clinical information on the 12 patients are listed in Table 1. The age of the patients ranged from 32 to 60 years. There were 8 males and 4 females. A total of 6 patients suffered from a traffic accident, 6 fell from a height, 5 patients suffered from fractures outside the axis, and three patients had pedicle fractures of the axis. After trauma, 11 patients showed normal neurological function, and 1 patient suffered from craniocerebral injury. The angle range of the vertebral body was $(0-17)^\circ$. The displacement range of the vertebral body was $(0-4.7)$ mm. One patient had a vertebral body angle that was larger than 11° , 3 had vertebral body displacements that were larger than 3.5 mm, and no patients showed both an angle larger than 11° and a displacement larger than 3.5 mm. A total of 5 patients were considered to have severe disc injuries. According to the treatment flow chart (Fig. 2), among the 6 patients with absolute instability, 4 patients were treated with anterior interbody fusion and internal fixation (Fig. 3 a-c), and 1 patient was treated with posterior fusion and screw rod fixation (Fig. 4 a). One patient had a vertebral body angle that was larger than 11° , and surgery was recommended. However, the patient requested conservative treatment (Fig. 5a-c). Of the 6 patients with relative instability, 3 underwent fixation

1 with screws (Fig. 6a). Three patients were treated conservatively (Fig. 7a). After 6-72
2 months follow-up, 12 patients finally achieved osseous fusion. One patient underwent
3 surgery, and one patient underwent conservative treatment and had mild neck
4 discomfort after working for long periods of time.

5 6 **Discussion**

7 TDFA is a rare upper cervical spine injury. The most common cause is traffic
8 accidents, followed by falls from a height [3-7]. Most scholars believe that the
9 mechanism of this phenomenon is hyperextension force acting on the forehead and
10 face region leading to rupture of the ALL at the anterior attachment of the axis and
11 causing avulsion fracture [3,5,6]. Some scholars also believe that axial compression
12 loading combined with hyperextension force is a damage mechanism [8].

13 Edeiken-Monroe et al. described hyperextension dislocation of the cervical spine
14 and illustrated its subtle radiographic features [9]. In previous studies in the literature,
15 TDFA-separated avulsion fragments usually show vertical dimensions exceeding the
16 transverse dimensions, accompanied by different degrees of fragment displacement
17 and rotation [3-6]. Watanabe [3] reported a case of TDFA in which translocation of the
18 fragment caused dysphasia due to compression of the oesophagus. Yang reported that
19 in cases of the fracture line being present over half of the lower endplate of the axis in
20 the sagittal plane, the fracture is often regarded as 'huge' and causes obvious C2-3
21 instability [10]. PVST swelling has also been observed on MRI, but the fragment size
22 and dislocation were not correlated with the severity of PVST swelling [3,4,6]. The
23 continuous transmission of violent force will result in angulation and posterior
24 displacement of the vertebral body and injury to the posterior structure. Korres [5] et
25 al. reported a posterior displacement of the vertebral body of 2-4 mm in 3 of 11
26 patients.

27 The cervical intervertebral disc is an important endogenous factor of cervical
28 spine stability, and this disc is more difficult to heal than other tissues [11].
29 Biomechanical response and retrospective studies have shown that disc injury is

1 significantly associated with cervical segmental instability [12,13]. MRI is the most
2 sensitive imaging modality for the detection of ligament and disc injury. Watanabe [3]
3 and Hu [4] used T2-weighted MRI to examine patients with C2-3 teardrop fractures
4 and found a high-intensity signal in the C2-3 disc space, which may suggest the
5 presence of a severe disc injury with haemorrhage. According to the disk injury
6 classification system proposed by Sander et al [14], grades 2 and 3 correspond to
7 injured disks. Disc injury can lead to accelerated degeneration, a loss of the correction
8 angle and progression of the deformity [15,16]. However, Malham et al. [17]
9 investigated the diagnostic properties of cervical MRI in detecting surgically verified
10 anterior longitudinal ligament (ALL) and intervertebral disc disruptions and showed
11 that the accuracy of the MRI-based diagnosis of ALL and intervertebral disc injury
12 was 48% and 81%, respectively. Research by Goradia [18] and Zhuge [19] has
13 suggested that in cases of acute cervical spine injury, MRI is moderately to highly
14 sensitive to specific ligament structures but may overestimate the extent of destructive
15 damage compared with of intraoperative observations. Hogan et al [20] studied the
16 CT and MRI findings of 366 patients with blunt cervical injury. The negative
17 predictive value of CT was 98.9% (362 / 366), and that of unstable injuries was 100%.
18 Malhotra et al. [21] reported that 1080 patients with blunt cervical spine injury
19 underwent CT and MRI examinations within 48 hours after injury. For unstable
20 injuries, the negative predictive value of CT was 98.5%. The authors believe that MRI
21 may only be useful for patients with persistent abnormal neurological examinations.

22 Traumatic cervical instability can cause chronic neck pain and nerve and spinal
23 cord compression. Images have served as important references for doctors to judge
24 fracture stability and formulate treatment plans. A biomechanical study defined
25 cervical instability as the horizontal displacement of one vertebra of more than 3.5
26 mm in relation to an adjacent vertebra as measured on lateral X-rays (resting or
27 flexion-extension) and a difference in rotation of more than 11 degrees relative to that
28 of either adjacent vertebra as measured on lateral X-rays (resting or flexion-extension)
29 [22].

1 In clinical work, scholars generally use intervertebral displacement (> 3.5 mm)
2 and/or intervertebral angulation (> 11 degrees) as indicators of instability of hangman
3 fracture and the lower cervical spine [23,24]. Lockey [25] suggested that dynamic
4 X-rays of the cervical spine should be taken as a basic examination to accurately
5 eliminate cervical instability. However, in a study of 1,000 patients, McCracken
6 concluded that adequate flexion-extension films are difficult to obtain and are
7 minimally helpful for evaluating cervical stability [26]. Khan suggested that flexion
8 and extension radiographs are not clinically useful in assessing acute instability in
9 hospitalized patients [27]. In recent years, CT has been used increasingly in screening
10 for cervical spine injury and obtaining measurements of the upper cervical spine
11 [28,29]. The American College of Radiology reported that CT images are preferred
12 over radiographs for the initial assessment of spine trauma. [28], and Batista [29] et
13 al. have suggested that in evaluating craniocervical junction malformations,
14 CT scans represent bone landmarks more precisely than plain radiographs.
15 However, Humphry [30] found that CT examination omitted cervical instability.
16 Clinicians should recognize the importance of physiological loading and recommend
17 that upright radiographs be used to detect clinical instability in patients with cervical
18 spine injury. One of our patients showed an angle larger than 11 degrees on the
19 upright lateral X-ray examination (Fig. 5a) but a small angle on the CT examination
20 (Fig. 5b). In 2007, the Spine Trauma Study Group [31] standardized the measurement
21 of C2-3 angulation and displacement. In a subsequent study, Bono [32] et al.
22 suggested that the intrarater and interrater reliability of C2-3 translation were higher
23 for plain radiographs than CT images. Watanabe [3] and Hu [4] used recommended
24 methods to measure displacement in TDFA.

25 Watanabe [3], Korres [5] and Boran [33], reported good clinical outcomes in
26 most patients with non-operative TDFA treatment. There were no cases of neck pain
27 associated with residual remaining deformity or C2-3 disc injury after conservative
28 treatment [3-5,30]. It is generally considered that a large fragment size, displacement
29 or angulation, intervertebral disc injury, neurological deficits, or signs of instability

are reasonable indications for surgical treatment [4,6-8,10,34]. Surgical treatment includes anterior, posterior and combined anterior and posterior approaches. Posterior surgery may provide better stability, but methods for anterior bone reduction and intervertebral disc injury treatment are lacking and may damage the posterior structure [4,34]. Anterior reduction and interbody fusion are used in most surgical patients [4,6-8,10]. Biomechanical studies have confirmed that anterior plate fixation has the same effect as posterior plate fixation in treating single-stage injuries [35]. Anterior stabilization is our preferred method because it reduces fracture fragments directly, removes damaged intervertebral discs, and facilitates restoration of the stability and physiological curvature of the anterior and middle columns of the spine.

Regarding our treatment plan (Fig. 2), when TDFAs are considered absolutely unstable, anterior or posterior fusion is recommended (Fig. 3/Fig. 4). Conservative treatment is recommended when TDFAs are considered relatively unstable. For patients undergoing conservative treatment (Fig. 7), if oesophageal compression leads to dysphagia or the patient cannot tolerate long-term external fixation, only screw fixation is recommended (Fig. 6); this approach is less traumatic than anterior fusion and provides immediate stability of the fracture. With an classification and treatment process, all patients achieved bone healing and good neck function. Two patients had slight neck discomfort after working for a long period of time, but we cannot be certain that this symptom is related to trauma or malunion.

This study showed good clinical results; because clinical cases of teardrop fractures are rare, there is no unified standard for the treatment of intervertebral disc and soft tissue injuries, and many clinical studies are needed to validate the results.

Conclusion

The treatment for TDFA should be determined by considering both the instability of the axial vertebra and the disease characteristics of the patients. With an appropriate classification and treatment process, both surgical and conservative treatment can yield good clinical outcomes.

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Abbreviations

TDFA: Teardrop fracture of the axis; PVST: prevertebral soft tissue; ALL: anterior longitudinal ligament; CT: Computed tomography; MRI: Magnetic resonance imaging

Author contributions

X and XL contributed to collected the cases and wrote the article. XX and CY analyzed them. XL and GL provided the research ideas. All authors have read and approved the final manuscript.

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Conflicts of Interest

There are no conflicts of interest to declare.

Ethics approval and consent to participate

All procedures performed in this study involving human participants were in accordance with the ethical standards of our institution and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The ethics committee of Hong Hui Hospital of Xi'an Jiaotong University and Ankang Center Hospital approved the project. All patients agreed that their clinical images and medical records for scientific report. Written informed consents were obtained from all participants if necessary.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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14 **Figure legends**

15 Figure1 RadiAnt DICOM Viewer Measurement of vertebral angulation(a) and
16 vertebral posterior displacement(b): X-ray

17 Figure2 Treatment flow chart

18 Figure3 Lateral cervical radiograph(a). T2-weighted MRI scan showing
19 hyperintensity in the C2-3 intervertebral disk and precervical soft tissue(b). Follow-up
20 Lateral cervical radiograph showed bony fusion at the C2-3 segment(c).

21 Figure4 Posterior internal fixation. X-ray showed that the lacrimal point was fixed
22 and healed 8 months after operation (a).

23 Figure5 Lateral X-ray angulation(a) 17 degree, CT slight angulation (b), bone healing
24 6 months after injury(c)

25 Figure6 Single screw fixation, postoperative follow-up showed bony healing(a).

26 Figure7 Conservative treatment, bone healing 6 months after injury(a).

Figures

Figure 1

RadiAnt DICOM Viewer Measurement of vertebral angulation(a) and vertebral posterior displacement(b):
X-ray

Figure 2

Treatment flow chart

Figure 3

Lateral cervical radiograph(a). T2-weighted MRI scan showing hyperintensity in the C2-3 intervertebral disk and precervical soft tissue(b). Follow-up Lateral cervical radiograph showed bony fusion at the C2-3 segment(c).

Figure 4

Posterior internal fixation. X-ray showed that the lacrimal point was fixed and healed 8 months after operation (a)

Figure 5

Lateral X-ray angulation(a) 17 degree, CT slight angulation (b), bone healing 6 months after injury(c)

Figure 6

Single screw fixation, postoperative follow-up showed bony healing(a)

Figure 7

Conservative treatment, bone healing 6 months after injury(a)