Original Article

Anterior C2–3 fusion with internal fixation for unstable teardrop fracture of the axis: a retrospective cohort study

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Background: Teardrop fracture of the axis (TDFA) is rare in cervical injuries. The treatment for TDFA is controversial, and few prior studies exist. C2–3 fusion with internal fixation could provide anterior support and ensure immediate stability. The aim of this study was to evaluate the clinical outcome of anterior C2–3 fusion with internal fixation for unstable TDFA.

Methods: Fifteen patients with unstable TDFA were treated by anterior C2–3 fusion with internal fixation between October 2012 and June 2018. Radiological parameters, including the avulsed ratio of the inferior endplate of the axis, the average rotation angle, and the displacement of the avulsed fragment, were measured before the operation. Clinical parameters, including the visual analogue scale (VAS) and the Neck Disability Index (NDI), were assessed before the operation; 3 days, 1 month, and 3 months after the operation; and at the final follow-up. Perioperative complications were also recorded.

Results: The mean follow-up time was 42.4 months (24–60 months). The mean operation time was 81.0 minutes (62–104 minutes), and the intraoperative blood loss was 61.3 mL (30–100 mL). Two patients complained of mild dysphagia after the operation and recovered at postoperative 1 month. Two patients classified as American Spinal Injury Association (ASIA) impairment scale grade D both improved to ASIA grade E postoperatively. The VAS score decreased from a preoperative value of 8.2±1.2 to a postoperative value of 1.7±0.9 (P<0.001), and maintained at 1.5±0.6 at last follow-up (P=0.51). The NDI score decreased from a preoperative value of 79.3±14.1 to a postoperative value of 16.5±4.3 (P<0.001), and maintained at 17.1±4.6 at last follow-up (P=0.62). No loosening or rupture of implantation was observed during the follow-up period. Bony union and fusion were achieved in all patients.

Conclusions: The clinical and radiological outcomes of anterior C2–3 fusion with internal fixation for the treatment of unstable TDFA were satisfactory. Anterior C2–3 fusion with internal fixation could be considered as a safe and effective method for managing TDFA.

Keywords: Axis; teardrop fracture; anterior; fusion

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Introduction

Teardrop fracture of the axis (TDFA) is defined as the avulsed fracture of the anterior-inferior part of the axis (1). This injury is rare and accounts for only 1–3% of cervical spine fractures, which are most commonly caused by motor vehicle accidents and falls (2).

Although most cases of TDFA can be treated conservatively, surgical treatment is theoretically preferable in cases of the unstable type. To date, no scholar has given an exact definition of "unstable" TDFA. Based on reported studies and our clinical experience, we consider a massive avulsed fragment, C2–3 intervertebral disc injury, and displacement of C2–3 ≥3 mm as features of an unstable fracture (3-5). To our knowledge, there are few reports on surgical procedures treating TDFA, and the optional surgical treatment for unstable TDFA remains controversial. In this study, we present our experience and the outcome of using anterior C2–3 fusion with internal fixation in the treatment of unstable TDFA. We present the following article in accordance with the STROBE reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-22-4020/rc).

Methods

Study design and patients

This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by Institutional Ethics Committee of Soochow University (No. 2022351), and written informed consent was obtained from all patients. The diagnosis of unstable TDFA was established when one of the following features was present: (I) a massive avulsed fragment, of which the avulsed ratio was over 1/3 (*Figure 1*); (II) C2–3 intervertebral disc injury; and (III) displacement of C2–3 ≥3 mm. The exclusion criteria included the following: (I) a pathologic fracture; (II) infection in the operative field; and (III) any serious general illness (e.g., heart failure).

From October 2012 to June 2018, 15 patients (4 females and 11 males) with unstable TDFA underwent anterior C2–3 fusion with internal fixation. The mean age of the patients was 43.7 years (33–68 years). The causes of their injuries included 8 cases of motor vehicle accident, 2 cases of falling from seated height, 4 cases of falling from greater than standing height, and 1 case of being hit by heavy objects. Eight patients had a forehead injury and 5 had a mandible injury. According to the American Spinal Injury Association (ASIA) impairment scale, 2 cases were grade D, and 13 cases were grade E. All patients complained of neck pain and restricted motion of their cervical spine. The patients' demographic data are shown in *Table 1*.

Preoperative managements and operative procedures

All the patients were hospitalized with skull traction. For the patients without C2–3 displacement, the traction weight was 2–3 kg. For those with C2–3 displacement, the traction weight was gradually increased until the displacement was reduced based on the subsequently reviewed radiographs.

All surgeries were performed by the same experienced surgeon. The patient was placed in the supine position with the neck extended under general anesthesia. A right-sided anterior horizontal incision was made midway between the angle of the jaw and the thyroid cartilage. The tissue was separated layer by layer, and the superior laryngeal nerve was carefully protected. After opening of the retropharyngeal tissue and prevertebral fascia, the anterior surface of C2–3 was clearly exposed. A pair of Caspar pins was fixed to the center of C2 and C3. The insertion point of the Caspar pin was 2 mm above the avulsed fragment for C2, and 8 mm below the superior endplate for C3. Discectomy was done routinely with the assistance of a Caspar distractor, and then the avulsed fragment was reduced and fixed using a Kirschner wire. A cage filled with autologous iliac bone was inserted into the intervertebral space of C2–3. A plate was implanted anteriorly, and 4 self-tapping screws were used to fix the fractured fragment and the plate. The final reduction and positions of the internal implant were confirmed by C-arm. Routine closure was performed, and a drain was left in place as needed for 24 to 48 hours.

Postoperative management

Antibiotics were administered on the first postoperative day, and dexamethasone and mannitol were administered for 3 days. Patients were allowed to walk on the third postoperative day but were required to wear a cervical collar, which was applied for 4 weeks. Radiographs were routinely taken on the third postoperative day. Patients were re-examined at postoperative 1, 3, and 6 months and annually thereafter.

Collected data and outcome assessment

Collected data included age, gender, intraoperative blood

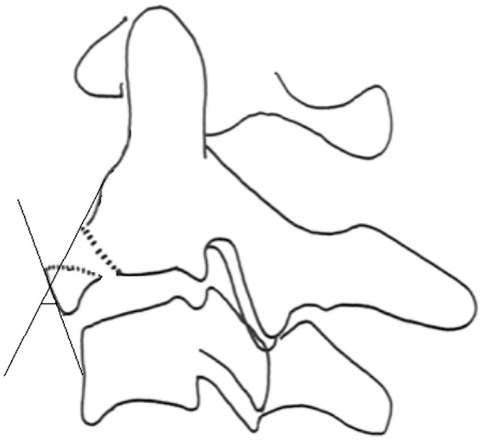

Figure 1 The rotation angle of the fractured fragment was measured as the intersection angle of the anterior surface of the axis and the anterior surface of the fragment.

loss, operative time, complications, and clinical and radiological outcomes.

Radiological assessment

The height, width, rotation angle, displacement of the fragment, and the avulsed ratio of the inferior endplate were measured in the lateral radiograph (*Figures 1*,*2*). Prevertebral soft-tissue swelling (PVST) was described as none, focal, or diffuse using the classification defined by Lee *et al.* (6). "Focal" was defined as limited to the level of the fracture, and "diffuse" was defined as extending to at least 1 vertebral level above and below the level of the fracture. The displacement of C2–3 was measured as the distance between lines drawn along the posterior aspect of C2 and C3 (7). C2–3 intervertebral disc injury was investigated by

Table 1 Demographic data of patients

Case	Age (yrs), sex	Injury	Preoperative ASIA grade	Operation time (min)	Intraoperative blood loss (mL)	Postoperative ASIA grade	Follow-up duration (months)
1	33, M	Motor vehicle accident	E	65	40	E	60
2	41, M	Motor vehicle accident	E	88	60	E	60
3	68, F	Fall from seated height	E	72	60	E	60
4	36, M	Motor vehicle accident	D	104	100	E	48
5	42, M	Hit by heavy objects	E	79	50	E	48
6	35, M	Motor vehicle accident	E	62	70	E	48
7	39, F	Fall from greater than standing height	E	71	50	E	48
8	48, F	Motor vehicle accident	E	68	60	E	48
9	47, M	Fall from greater than standing height	E	86	30	E	36
10	40, M	Motor vehicle accident	E	74	60	E	36
11	36, M	Fall from greater than standing height	E	88	80	E	36
12	48, M	Motor vehicle accident	D	100	100	E	24
13	65, F	Fall from seated height	E	91	70	E	36
14	37, M	Motor vehicle accident	E	87	40	E	24
15	40, M	Fall from greater than standing height	E	80	50	E	24

ASIA, American Spinal Injury Association.

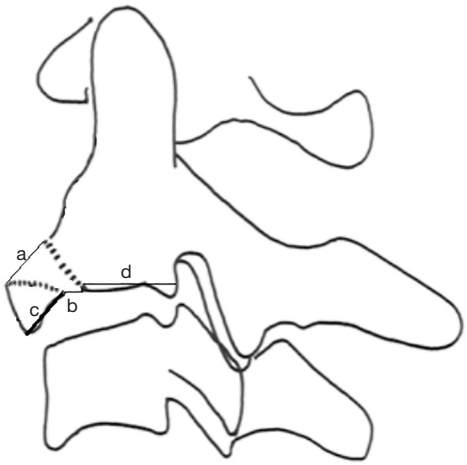

Figure 2 The displacement of the fragment was measured as the mean length at the superior point and the posteroinferior point of the fractured fragment: (a+b)/2. The avulsed ratio of inferior endplate was measured as c/(c+d).

magnetic resonance imaging (MRI).

Clinical assessment

The ASIA impairment scale (8) was used to evaluate the neurological status. The visual analogue scale (VAS) (9) was used to evaluate pain, and the Neck Disability Index (NDI) (10) was used to assess neck function.

Statistical analysis

The clinical and radiological data were evaluated and recorded by 2 independent observers. Comparisons of the pre- and postoperative assessments were analyzed using a paired sample *t*-test. All the analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 13.0 (IBM Corp., Armonk, NY, USA). The results of two-sided tests were considered statistically significant when P was less than 0.05.

Results

All 15 patients tolerated the procedure well. The mean follow-up was 42.4 months (24–60 months). The mean operation time was 81.0 minutes (62–104 minutes), and blood loss was 61.3 mL (30–100 mL; *Table 1*). There were significant improvements in the VAS and NDI scores at the postoperative follow-up assessments compared with the preoperative values (*Table 2*). Two patients classified as ASIA grade D both improved to ASIA grade E at postoperative 6 months.

No major perioperative complications occurred, including spinal cord injury, superior laryngeal nerve injury, or esophageal injury. Two patients complained of mild dysphagia 3 days postoperation and recovered at postoperative 1 month. No loosening or rupture of implantation was observed during the follow-up period.

The mean height of the fragment was 9.5 mm (7.3–12.3 mm), and the mean width was 7.2 mm (5.9–8.5 mm; *Table 3*). The average avulsed ratio of the inferior endplate of the axis was 40.6% (33.7–51.2%). The mean displacement of the fragment was 4.6 mm (3.5–6.1 mm), and the rotation angle of the fragment was 23.8° (10.8–31.5°). Displacement of C2–3 was observed in 2 patients, with a displacement of 3 mm and 4 mm, respectively. C2–3 intervertebral disc injury was found in all 15 patients. "Diffuse" PVST swelling was found in 13 patients, and "focal" PVST swelling was found in 2 patients. All patients achieved bony union and fusion at postoperative 6 months (*Figure 3*). There were no cervical malformations or instability during the follow-up period.

Discussion

Teardrop fracture was first described by Kahn and Schneider in 1956 (1). In the lower cervical spine, teardrop fractures are usually incurred in flexion (11). In contrast, teardrop fractures of the axis are commonly caused by the hyperextension of the cervical spine with a direct high-energy blow to the forehead or mandible (12,13). During the process of hyperextension, the odontoid process acts as a moment arm and the posterior bony elements act as a fulcrum, and the anterior lower corner of the C2 vertebra is avulsed by distension of the anterior longitudinal ligament. In our study, most (13/15) patients had injuries of varying severity on the forehead or mandible, suggesting the injury mechanism of TDFA was hyperextension.

Different injury mechanisms may lead to fractures that seem to be similar at radiological manifestation. TDFA should be distinguished from hyperextension dislocation fracture of the axis. Edeiken-Monroe *et al.* (14) noted that the vertical height of the avulsed fragment in TDFA is equal to, or exceeds, its horizontal width, whereas in hyperextension dislocation fracture, the transverse dimension of the fragment is greater than the vertical dimension. In the current study, the mean height and width

Table 2 Mean improvement in VAS and NDI

	Preoperative	Postoperative 3 days	Postoperative 1 month	Postoperative 3 months	Last follow-up
VAS score	8.2±1.2	3.6±0.9[a]	1.8±0.8[a]	1.7±0.9[a]	1.5±0.6[ab]
NDI (%)	79.3±14.1	48.6±8.0[a]	32.9±7.2[a]	16.5±4.3[a]	17.1±4.6[ac]

Data are presented as mean ± standard deviation. [a], P<0.001 (compared with preoperative); [b], P=0.51 (compared with postoperative 3 months); [c], P=0.62 (compared with postoperative 3 months). VAS, visual analogue scale; NDI, Neck Disability Index.

Table 3 Radiologic measurements of TDFA

Case	Height (mm)	Width (mm)	Displacement (mm)	Rotation angle (°)	Avulsed ratio (%)	C2–3 displacement (mm)	PVST swelling
1	8.7	6.9	4.3	10.8	33.7	0	Diffuse
2	9.8	7.9	3.8	31.5	38.3	0	Diffuse
3	10.9	6.9	3.5	24.5	39.5	0	Focal
4	7.3	7	3.7	30.2	33.9	3	Diffuse
5	11	7.1	6.1	28.2	49.1	0	Diffuse
6	9.5	6.4	4.8	27.1	34.6	0	Diffuse
7	9.8	7.2	4.5	18.2	41.2	0	Diffuse
8	10.2	6.8	4.9	28.6	43.2	0	Diffuse
9	12.3	8.0	4.7	27.2	37.7	0	Diffuse
10	10.1	7.7	4.1	21.3	45.1	0	Diffuse
11	8	5.9	4.4	20.6	40.6	0	Diffuse
12	9.2	8.5	5.3	30	51.2	0	Diffuse
13	8.2	7.8	3.6	24.3	38.9	4	Focal
14	9	7.5	5.3	20.6	45	0	Diffuse
15	9.2	7.8	5.7	17.8	34.1	0	Diffuse

TDFA, teardrop fracture of the axis; PVST, prevertebral soft-tissue swelling.

of the fragment were 9.5 and 7.2 mm, respectively, and this finding was consistent with previous reports.

In previous decades, it was thought that TDFA occurred commonly in older patients with osteopenia and was associated with minimal or no PVST swelling. However, in recent studies (3,15), many authors have reported that TDFA occurs predominantly in young patients due to a higher rate of motor vehicle accidents and aloft work. In the present study, the mean age of the patients was 43.7 years (33–68 years). Burke and Harris (16) reported that PVST swelling was minimal in elderly patients but diffuse in young patients. Consistent with this finding, in our study, minimal PVST swelling was found in 2 elderly female patients (cases 3 and 13) who fell from seated height, and diffuse PVST swelling was found in 13 younger patients who were injured by high-energy trauma.

To date, an exact definition of unstable TDFA has not been established. The anterior-inferior part of the C2, from where the anterior longitudinal ligament originates, is the main load bearing area and plays a crucial role in extension and flexion movement of the cervical spine. Massive TDFA is usually associated with rupture of the anterior longitudinal ligament and C2–3 intervertebral disc injury. In the surgical procedure, we found that the avulsed fragment was usually attached to the ruptured anterior longitudinal ligament, and the C2–3 intervertebral disc was avulsed from the C2 inferior endplate. As we know, the intervertebral disc consists of nonvascular tissue and has very limited self-repair capacity after disc damage (17). In addition, segmental translation exceeding 3 mm leads to cervical instability (4). Therefore,

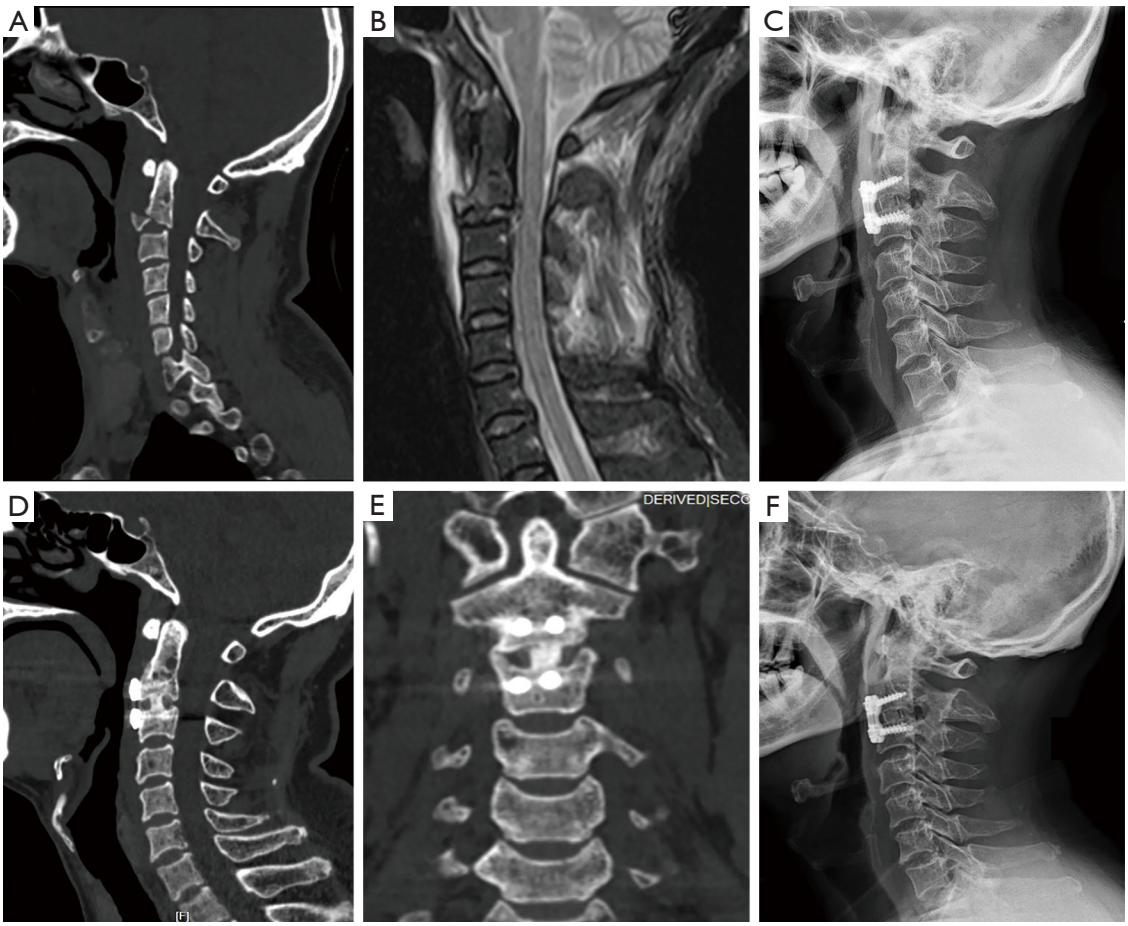

Figure 3 A 48-year-old male patient sustained TDFA from motor vehicle accident. (A) Preoperative CT showed the TDFA. (B) The preoperative MRI displayed C2–3 disc rupture and the presence of mild spinal cord compression. (C) The postoperative lateral radiograph showed adequate fracture reduction and C2–3 fusion with internal fixation. (D,E) The CT scan at postoperative 3 months showed solid bone union and fusion. (F) The lateral radiograph at last follow-up showed good stabilization and normal lordosis of cervical spine. CT, computed tomography; TDFA, teardrop fracture of the axis; MRI, magnetic resonance imaging.

we consider that unstable TDFA should be diagnosed in TDFA when one of the following features is present: (I) a massive avulsed fragment; (II) C2–3 intervertebral disc injury; and (III) displacement of C2–3 ≥3 mm.

The optimal treatment for TDFA has been controversial. In previous studies, most cases of TDFA were treated conservatively and obtained satisfactory outcomes; however, most of these fractures were stable or small in size (1,13). Surgical stabilization is recommended for cases of the unstable type. Different surgical approaches, both anterior and posterior, have been reported for treating TDFA (18,19). Posterior fixation can provide better stability. However, it may cause iatrogenic damage to the posterior structures such as the ligaments and muscles. Moreover, the avulsed fragment can't be reduced, and the damaged intervertebral disc can't be addressed, which may cause chronic dysphagia and cervical kyphosis.

In this study, we performed anterior reduction, discectomy, and fusion with an anterior plate via a high anterior cervical approach to treat unstable TDFA. The advantages of this procedure were as follows: (I) the avulsed fragment, which may compress the esophagus and lead to dysphagia, could be reduced and fixed directly. (II) The instability at the injured disc could be addressed, and decompression could be achieved directly. In our study, 2 patients classified as ASIA grade D improved to ASIA grade E postoperatively. (III) The procedure could provide anterior support, ensure immediate postoperative stability, and enhance the bony

union and fusion. In our study, patients were allowed early mobilization 3 days postoperation. All the patients obtained solid bony union and fusion at postoperative 6 months. (IV) Our procedure was less invasive and was associated with less blood loss compared with posterior fixation. In this study, the mean operation time was 81.0 minutes, and blood loss was 61.3 mL.

Despite the advantages, this approach is technically demanding. Care must be taken not to damage the vital structures, such as the facial and hypoglossal nerves, the superior laryngeal nerves, and the carotid arteries. In our study, no major perioperative complications occurred. Two patients (case 4 and 12) complained of mild dysphagia and recovered at postoperative 1 month, which might be attributed to relatively longer intraoperative esophagus retraction time.

This study had several limitations. First, it was retrospective, and the number of patients was small. Second, it was limited by the lack of a posterior surgical procedure or conservative treatment control group. In addition, the definition of unstable TDFA is vague, and we only considered 3 factors. Further specialized systematic studies are required to establish sound evaluation criteria.

Conclusions

The clinical and radiological outcomes of anterior C2–3 fusion with internal fixation for the treatment of unstable TDFA were satisfactory. Anterior C2–3 fusion with internal fixation could be considered as a safe and effective method for managing TDFA.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://atm.amegroups.com/article/view/10.21037/atm-22-4020/rc

Data Sharing Statement: Available at https://atm.amegroups.com/article/view/10.21037/atm-22-4020/dss

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-22-4020/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This retrospective study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by Institutional Ethics Committee of Soochow University (No. 2022351), and written informed consent was obtained from all patients.

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