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ORIGINAL PAPER

Multicentre comparative study of Z-shape elevating–pulling reduction and skull traction reduction for treatment of lower cervical locked facets

Xinjia Wang[1] · Weibin An[1] · Qiang Wu[2] · Shanpeng Wu[3] · Guoxin Li[4] · Jican Zeng[1] · Yuchun Chen[1] · Guanfeng Yao[1]

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Abstract

Purpose The aim of this study was to assess the clinical efficacy and safety of Z-shape elevating–pulling reduction as compared to that of conventional skull traction in the treatment of lower cervical locked facet.

Methods Patients with cervical locked facet ($n = 63$) were retrospectively enrolled from four medical centers and divided into two groups according to the pre-operative reduction method used: Z-shape elevating–pulling reduction (Z-shape elevating group; $n = 20$) or traditional skull traction reduction (skull traction group; $n = 43$).

Results The success rates, efficacy of reduction, and safety were compared between the two groups. The success rates were significantly better in the Z-shape elevating group than in the skull traction group: 87.5% (7/8) vs. 35.3% (6/17) for unilateral locked facet reduction ($P = 0.03$) and 100% (12/12) vs. 69.2% (18/26) for bilateral locked facet reduction ($P = 0.04$). There was no obvious change in American Spinal Injury Association (ASIA) grade after the reduction in either group. Combined surgery was necessary in 5% in the Z-shape elevating group vs. 27.9% in the skull traction group. Imaging showed that the segment angle and horizontal displacement were significantly improved after surgery in both groups, with no significant difference between the groups. Follow-up with radiography showed good recovery of the cervical spine sequence; all internal fixation sites were stable, with no loosening, prolapse, or breakage of internal fixators.

Conclusions Halo vest–assisted Z-shape elevating–pulling reduction appears to be a simple, safe, and effective technique for pre-operative reduction of lower cervical locked facets.

Keywords Subaxial cervical dislocation · Locked facet · Halo-vest · Z-shape elevating–pulling reduction · Skull traction

Background

Traumatic subaxial cervical dislocation may present with unilateral or bilateral locked facet joints [1]. Early reduction can improve neurological outcome [2, 3] and simplify surgery. Closed reduction of fracture–dislocation injuries of the cervical spine by traction–reduction is safe and effective in awake patients [4, 5]. Skull traction—the most commonly used method—is a simple procedure to achieve early reduction and relieve spinal cord compression [6–13]. It stabilizes and reconstructs the sequence of the cervical spine and helps prevent secondary damage. However, the success of skull traction depends on various factors, such as the type of dislocation (unilateral vs. bilateral), traction weight, interval between increases in traction weight, presence of associated fracture of articular process or soft tissue embedding, time since dislocation, and so on. Moreover, while the success rate of skull traction is ~76% in cases of bilateral locked facet, it is only 14–36% in cases of unilateral locked facet [6–13]. The main reason for the low success rate in the latter is that skull traction cannot control the rotational force. Skull traction involves the use of ropes and straps, and the neck is mostly in a fixed position, which makes correction of any rotational deformity difficult.

The mechanism of causation of unilateral cervical facet locking is fairly well understood. Combined flexion and rotational forces lead to the separation of the facet joint; the inferior facet process of the upper vertebra is displaced and comes

Qiang Wu, Shanpeng Wu and Guoxin Li contributed equally to this work.

✉ Xinjia Wang
xj.wang2000@163.com

1 Department of Spine Surgery, the Second Affiliated Hospital, Shantou University Medical College, Shantou 515041, Guangdong, People's Republic of China

2 Yuebei People's Hospital, Shaoguan 512026, Guangdong, People's Republic of China

3 Quanzhou First Hospital, Fujian Medical University, Quanzhou 362000, Fujian, People's Republic of China

4 Peking University Shenzhen Hospital, Shenzhen 518036, Guangdong, People's Republic of China

to lie anterior to the superior facet process of the lower vertebrae. Due to coupling and conjugation of the bilateral facet joints of the cervical spine, the facet joint on one side is locked while the joint on the other side is subluxated. In unilateral locked facet joint, there exists not only flexor–extension tension but also rotational tension. This makes resetting of a unilateral locked facet more difficult than that of bilateral locked facets.

We developed a new Z-shape elevating–pulling reduction technique and have successfully applied it for reduction of bilateral and unilateral locked facets. The method is simple, and preliminary results show high success rates [14, 15]; however, there have been no studies comparing its efficacy with that of skull traction reduction. The aims of this retrospective multicentre study were to compare Z-shape elevating–pulling reduction with the traditional skull traction technique in the treatment of lower cervical locked facets and to evaluate its feasibility, effectiveness, and safety.

Materials and methods

Study design and patients

The retrospectively enrolled population of this study comprised patients with cervical locked facet treated at four medical centres—the Second Affiliated Hospital of Shantou University Medical College, Yue Bei People's Hospital of Shaoguan, Quanzhou First Hospital of Fujian Medical University, and Peking University Shenzhen Hospital—between June 2011 and December 2014. Patients were eligible for inclusion if they (1) were between the ages of 18 and 65 years; (2) had definite history of trauma; (3) had symptoms and signs (neck pain, deformity, or restriction of cervical extension, flexion, and rotation after suffering the trauma), with or without paralysis of limbs; (4) had radiographic evidence of dislocation of cervical vertebra (facet joint "interlocking" on oblique radiographs and/or dislocation of the cervical spine and a "jump sign" of the articular process in CT), with or without vertebral or other fractures. All patients underwent radiography, three-dimensional CT reconstruction, and MRI of the cervical spine to exclude nontraumatic spinal cord lesions such as inflammation, degeneration, tumour, vascular disease, and congenital disease, as well as to rule out any contraindication to closed reduction.

The enrolled patients were separated into two groups according to the pre-operative reduction method: halo vest–assisted Z-shape elevating–pulling reduction (Z-shape elevating group) or skull traction reduction (skull traction group). All reductions were performed by experienced spine surgeons with more than 20 years' experience in spinal surgery. Allocation of the study patients to different treatments was primarily based on the individual surgeon's preference and experience. This study was approved by the Ethics Committee of our institution. All patients signed informed consent.

Halo vest-assisted Z-shape elevating–pulling reduction technique

The halo vest was installed as usual. Reduction was performed after ensuring that the patient's vital signs were stable. Three main steps were carried out during the reduction [14, 15]. To aid understanding, each screw of the bolts is shown in Fig. 1. The three steps of the reset process were as follows:

Step 1: Bolts A (A′), B (B′), and D (D′) were unscrewed; D (D′) was tightened after the bolts attached to the support at the back of the head ring was lifted 2–3 cm.

Step 2: Bolt C (C′) was loosened; the bolts on the support bar in front of the head were lifted by 2–4 cm, and then C (C′) was tightened again.

Steps 1 and 2 were repeated till reduction of the locked facet was achieved.

Step 3: The above steps were performed in reverse to gradually lower the head ring on the support rod bolts till the normal height of the cervical spine was restored.

For unilateral joint locking reduction, the above steps were performed to achieve the same bilateral facet locking. First, "tip to tip" reset was performed, and then, the injured side was raised 1–2 cm and the healthy side depressed 2–3 cm to complete the reduction.

Operation method

When closed reduction was successful, the anterior approach was used for surgery. Patients with vertebral fracture received anterior subtotal corpectomy, titanium mesh, and plate fixation, while patients without vertebral fracture received discectomy, decompression + cage bone grafting, and internal fixation. When closed reduction failed, anterior reduction and internal fixation was performed first. If the operation failed, anterior–posterior–anterior combined approach operation or simple posterior approach was performed. Internal fixation with pedicle screw rod system or lateral screw internal fixation was performed at the posterior cervical spine.

Observation index

The primary observation index was the reset success rate. The secondary observation index was the American Spinal Injury Association (ASIA) grades at admission and at final follow-up and the proportion of patients receiving combined anterior and posterior surgery. The changes in the horizontal displacement rate (Fig. 2a), the segment angle (Fig. 2b), and the height ratio

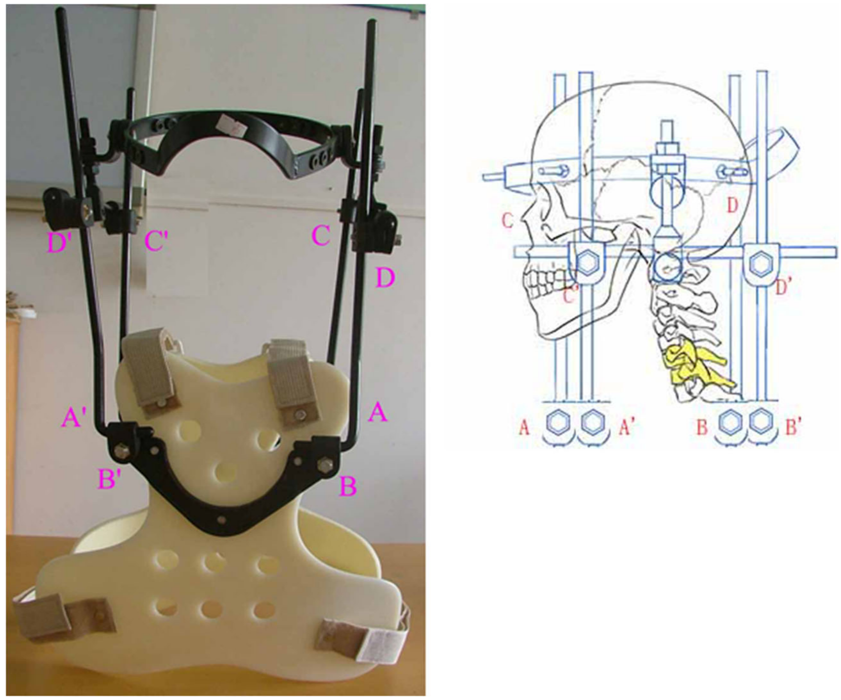

Fig. 1 Halo screw labels. A, A′ are the front lower; B, B′ are the rear lower; C, C′ are the front upper; D, D′ are the rear upper

of the vertebral body (Fig. 2c) were measured before and after the operation [16, 17].

Statistical analysis

SPSS 17 (SPSS Inc., Chicago, IL, USA) was used for data analysis. Measurement data were summarized as means and compared using Student's *t* test. Enumeration data were summarized as percentages and compared using Fisher's exact test. The two independent samples nonparametric test was used to compare group data. $P \leq 0.05$ indicated statistically significant difference.

Results

A total of 63 patients (52 men, 11 women) with lower cervical locked facet were enrolled. The ages of the patients ranged from 19 to 64 years (mean age, 44 years). Halo vest–assisted Z-shape elevating–pulling reduction was applied in 20 patients and skull traction reduction in 43 patients. Table 1 shows the baseline characteristics of the two groups.

Comparison of reduction success

For unilateral locked facet, reduction was successful in 7/8 (87.5%) patients in the Z-shape elevating group vs. 6/17 (35.3%) patients in the skull traction group; the difference was statistically significant ($P = 0.03$). For the bilateral joint locking, reduction was successful in 12/12 (100%) patients in the Z-shape elevating group vs. 18/26 (69.2%) in the skull traction group; the difference was statistically significant (Fisher exact test, $P = 0.039$) (Table 2).

Safety of reduction as assessed by neurological function evaluation

The ASIA grades of patients were recorded at admission, one day before reduction, and one day after reduction. No neurological deterioration was seen in either of the two groups. However, in the skull traction group, two patients (one grade A and the other grade B) developed respiratory failure when traction weight was increased (to 12 kg in one patient and to 14 kg in the other); in both cases, skull traction was removed and the patients transferred to the intensive care unit for ventilator-assisted breathing (Table 3).

Imaging evaluation

Radiographs and CT films of the cervical spine obtained before operation, after operation, and during follow-up were examined. All the internal fixation sites were stable; no loosening, prolapse, or fractures of the internal fixators were found. Horizontal displacement, segment angle, and intervertebral space height ratio were measured on the pre-operative and post-operative CT images.

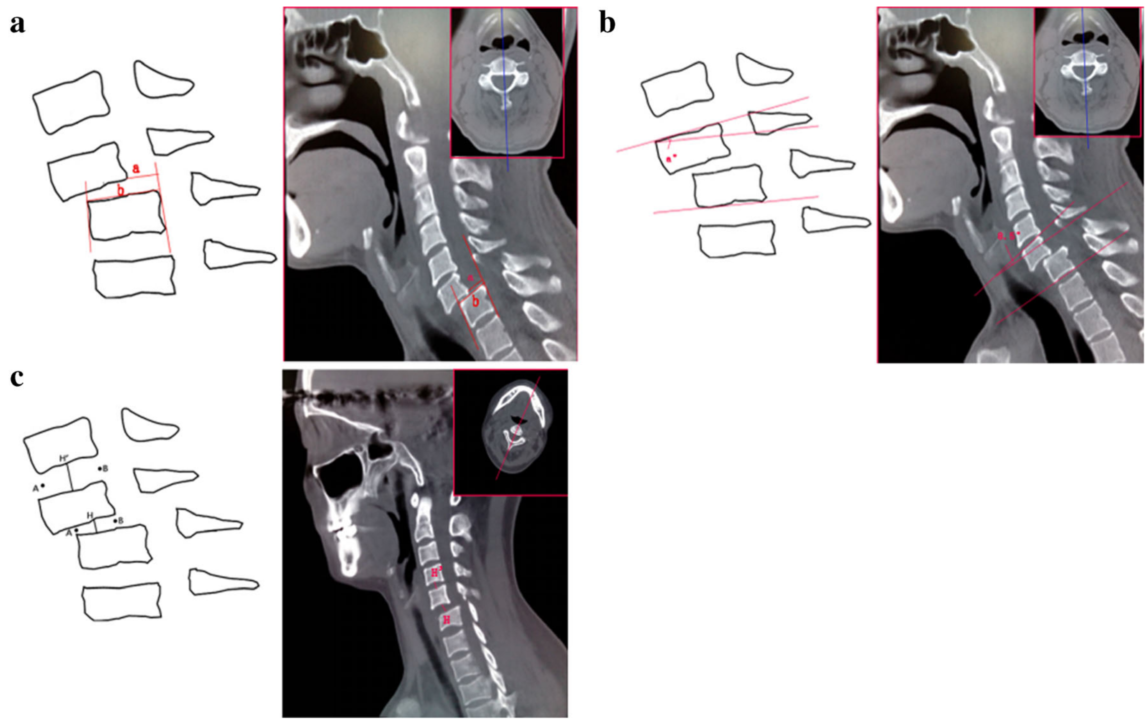

Fig. 2 Changes in the horizontal displacement rate (**a**), the segment angle (**b**), and the height ratio of the vertebral body (**c**)

Table 1 Baseline characteristics of patients in the two groups

Characteristics	Z-shape elevating group	Skull traction group	Test value	*P*
Age	44.35 ± 12.47	43.98 ± 11.42	0.117	0.907
Gender			0.123	0.726
Male	17	35		
Female	3	8		
Lock type			0.001	0.972
Unilateral	8	17		
Bilateral	12	26		
Fracture of articular process	9	26	1.102	0.294
Preoperative ASIA grade				
A	2	4	0.008	0.996
B	5	11	0.002	0.961
C	6	13	0.001	0.985
D	4	10	0.084	0.772
E	3	5	0.14	0.701
Damaged segment				
C3/4	1	3	0.09	0.765
C4/5	2	9	1.132	0.478
C5/6	8	13	0.586	0.444
C6/7	9	18	0.055	0.815
Associated injury				
Thoracic spine injury	7	6	3.692	0.092
Fracture of thoracic and lumbar spine	3	1	3.688	0.09
Fracture of the extremities	2	6	0.192	

Table 2 Comparison of success rate of reduction of locked facet by the different reduction methods

Group	Unilateral		Bilateral	
	Success	Failure	Success	Failure
Z-shape elevating group	7 (87.5%)	1 (12.5%)	12 (100%)	0 (0%)
Skull traction group	6 (35.3%)	11 (64.7%)	18 (69.2%)	8 (30.8%)

Note: Fisher's exact test was applied to compare differences between the groups. For unilateral locked facet: $X^2 = 5.94$, $P = 0.03$; for bilateral locked facet: $X^2 = 4.677$, $P = 0.039$

Horizontal displacement rate changes

The mean pre-operative and post-operative horizontal displacement rates were 39.17 ± 12.41 and 4.42 ± 2.7%, respectively, in the Z-shape elevating group, and 35.11 ± 19.75 and 5.89 ± 3.64%, respectively, in the skull traction group. The difference between the two groups in the pre-operative and post-operative displacement rates was not statistically significant ($P = 0.479$ and $P = 0.179$, respectively). However, in both groups, the difference between pre-operative and post-operative displacement rates was statistically significant ($P < 0.001$ in the Z-shape elevating group and $P < 0.001$ in the skull traction group).

Segment angle changes

The mean pre-operative and post-operative segment angles were 8.55° ± 5.58° and − 2.15° ± 1.52°, respectively, in the Z-shape elevating group, and 8.62° ± 6.5° and − 1.58° ± 1.12°, respectively, in the skull traction group. The difference between the two groups in pre-operative and post-operative segment angles was not statistically significant ($P = 0.974$ and $P = 0.159$, respectively). However, in both groups, the difference between pre-operative and post-operative segment angles was statistically significant ($P < 0.001$ in the Z-shape elevating group and $P < 0.001$ in the skull traction group).

Intervertebral space height ratio changes

The mean pre-operative and post-operative intervertebral space height ratios were 70.55 ± 14.55 and 108.35 ± 9.9%, respectively, in the halo vest group, and 72.43 ± 13.75 and 108.59 ± 9.5%, respectively, in the skull traction group. The difference between the two groups in pre-operative and post-operative intervertebral space height ratios was not statistically significant ($P = 0.671$ and $P = 0.953$, respectively). However, in both groups, the difference between pre-operative and post-operative intervertebral space height ratio was statistically significant ($P < 0.001$ in the Z-shape elevating group and $P < 0.001$ in the skull traction group).

From the above, it is apparent that cervical spine sequence, intervertebral space height, and kyphosis deformity were all corrected, with no significant difference in reduction efficacy between the two groups.

Operative approach

In the Z-shape elevating group 1, patient was treated by combined anterior and posterior approach and the others by simple anterior approach. In the skull traction group, 12 patients were treated by a combined anterior and posterior approach, six patients by simple posterior approach, and 25 patients by simple anterior approach.

Complications

No complications occurred in the Z-shape elevating group. In the skull traction group, six patients had pulmonary infection (one case occurred at the time of admission, one case occurred in the course of surgery, and four cases occurred after the operation); two patients had respiratory failure (one patient died of respiratory failure at four months after operation); two patients developed bedsores (sacral decubitus in one patient and occipital, sacrococcygeal, and decubitus ulcers in another).

Follow-up

Over follow-up, ranging from 14 to 33 months, neural function was recovered in all patients. Comparison of ASIA scores at admission and at final follow-up (excluding patients with ASIA score of E at admission) showed good neurological function recovery in both groups. In the Z-shape elevating group, reduction was markedly effective (i.e., ASIA grade increase over two levels) in five patients, effective (i.e., ASIA grade increase by 1 level) in seven patients; and produced no change (ASIA grade unchanged) in five patients. In the skull traction group, reduction was markedly effective in 12 patients, effective in 15 patients, and produced no change in 11 patients. The difference between the two groups was not statistically significant ($Z = -0.116$; $P = 0.907$). In the skull traction group, one patient with pre-operative ASIA grade of A died 4 months after operation because of respiratory failure.

Table 3 ASIA grade of patients in the two groups at different time points

AISA grade	Z-shape elevating group			Skull traction group		
	Day of admission	1 day before reduction	1 day after reduction	Day of admission	1 day before reduction	1 day after reduction
A	2	2	2	4	4	4
B	5	5	5	11	10	10
C	6	5	5	13	14	14
D	4	5	5	10	9	9
E	3	3	3	5	6	6

ASIA American Spinal Injury Association

Radiographs and CT films of the cervical spine during follow-up showed good healing at the internal fixation sites, with no loosening, prolapse, or fracture of the internal fixators.

Discussion

With improvements in technique, cervical spine surgery has become a reliable treatment for lower cervical facet joint locking [18–21]. Although there are differing views on whether or not to perform closed reduction before surgery, there is no doubt that pre-operative reduction greatly simplifies the surgical procedure [22].

Skull traction is mainly used to achieve closed reduction. It can provide immediate stability, help in rapid relief of spinal cord compression, and reconstruct the cervical spine sequence. While it can make subsequent operation easier, failure rates are reported to be high [6–13]. YU [6] reviewed 38 patients treated by rapid skull traction for cervical dislocation and locked facet following cervical injury. Closed reduction was successful in 88.0% of patients with bilateral cervical locked facets and 15.4% of patients with unilateral cervical locked facets. Chen et al. [8] retrospectively analyzed 68 patients with lower cervical fracture–dislocation and locked facet. Closed reduction with skull traction was successful in 54.4% of all patients; the success rates in bilateral cervical locked facets and unilateral cervical locked facet were 75.6 and 22.2%, respectively). In a multicentre North American prospective cohort study, Wilson et al. [1] reported successful reduction using skull traction in 40 of 48 (83%) cases of bilateral facet locking. O'Connor et al. [16] used skull traction to reset lower cervical locked facet in 21 patients, but reported success in only 11 patients (52%). In the present study, the success rate with skull traction was 35.3% in unilateral locked facet and 69.2% in bilateral locked facet; these results are similar to the results reported by others.

Various factors affect the success rate of reduction, including traction angle, traction weight, duration of traction, time from injury to reduction, interlocking type of articular process, presence of fracture of articular processes, and so on. Some authors have adopted high-dose traction [17, 23] and achieved satisfactory results. However, excessive traction could aggravate neurological and vertebral artery injuries or spinal fractures. In this study, the maximum weight used for skull traction was only 18 kg, which may be an important reason for the low success rate of reduction in bilateral locked facet. In addition, while rotational stress is an important mechanism causing unilateral locked facet, this is not taken into consideration during skull traction, and only an axial force is applied; this affects the efficacy of reduction.

Some scholars have used the halo vest for treatment of lower cervical fracture and dislocation, mostly as an external fixation device for conservative management [24]. It is relatively difficult to treat lower cervical locked facet, especially unilateral locking. In the present study, 20 patients with lower cervical locked facet (8 with unilateral locking and 12 with bilateral locking) were treated with halo vest, and reduction was successful in 19 patients. Reduction failed in one patient with unilateral locking, the reason being the presence of a large amount of callus in the fracture of the locked facet joint.

We identified some reasons for the high success rate of reduction with halo vest–assisted Z-shape elevating–pulling reduction. The halo vest can be fixed in three dimensions and can also help in complete three-dimensional adjustment of the cervical spine; that is, anterior flexion, lateral flexion, and rotational movement can all be controlled by adjustment of the stent. In clinical practice, halo vest is usually used to fix the cervical vertebra. Adjustment of the double-screw bolt may not always be able to provide sufficient distraction for resetting of the locked facet. In the new technique, when fixing the halo vest, sufficient length is intentionally reserved in the support bar to permit more traction distance through the halo vest struts (Fig. 1); with this, enough traction can be applied to achieve complete reduction of the dislocated facet. The slight anterior flexion of the cervical spine is caused by posterior distraction, and after the "tip-to-tip" state is reached, the inferior articular process is easily slipped behind to complete the reset. With sufficient anterior distraction, the dislocated vertebral body can be moved backwards, and the kyphotic deformity can be corrected.

There could be several reasons for the high success rate of the halo vest–assisted Z-shape elevating–pulling reduction technique. First, repeated lifting by the halo stent not only increases the axial distraction distance but also firmly fixes the dislocated articular process joint in a certain state (e.g., the tip-to-tip state) during the reset process, preventing any loss in reduction during subsequent procedures and position changes. Second, Z-shaped repeated lift traction can dynamically adjust the flexion and extension angle to avoid the "impact" of the locked facet and thus help in "unlocking" and resetting of the joint.

Rotational forces are involved in the genesis of unilateral facet dislocation. Clinical experience has shown that flexion–extension traction alone is not sufficient for achieving reduction of unilateral locked facet joints [6]. It is also necessary to have simultaneous forward flexion and lateral flexion on the basis of axial traction. The forward flexion and lateral flexion not only help decrease the impact between the locked facet joints, but also resets the rotational dislocation of the facet through the coupling movement [25]. During skull traction, the neck of the patient is in a comparatively fixed position. Moreover, the rotated articular processes are prone to "impact,' that is, the articular processes on the dislocated side will be locked in a hyperflexed position, while the articular processes on the contralateral side will be locked in a hyperextended position. The force applied during skull traction is along the direction of the rope, and this tends to aggravate vertebral rotation rather than control it. Thus, with skull traction, it is difficult to unlock and correct rotatory dislocation of the vertebral body. However, the Z-shape elevating–pulling reduction technique can correct the flexion or rotation factors of cervical spine. It can also precisely control and maintain the needed distraction distance with accurate three-dimensional fixation and thus improve success of reduction. The safety of closed reduction was also assessed. No neurological deterioration was seen in either of the two groups in this study. However, two patients in the skull traction group had unstable vital signs during the traction. We believe that skull traction, and especially rapid skull traction reduction using large weights, is more likely to stretch the spinal cord. The reason why halo vest–assisted Z-shape elevating–pulling reduction is safer could be that reduction is completed after repeated flexion–extension; in this process, articular process and vertebral body are positioned at opposite edges, which cause a great range of motion in the process of flexion and extension traction. However, the spinal cord lies at the centre of the spinal column; in this position, it is relatively stable and protected from the possibility of injury.

Conclusion

In conclusion, halo vest–assisted Z-shape elevating–pulling reduction appears to be a simple, safe, and effective method for reduction of lower cervical facet joint locking and may provide better results than skull traction.

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Compliance with ethical standards

This study was approved by the Ethics Committee of our institution. All patients signed informed consent.

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was approved by the Ethics Committee of the Second Affiliated Hospital, Shantou University Medical College. All patients signed informed consent.

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