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ORIGINAL ARTICLE

Clinical and radiological outcomes of one-level cervical corpectomy with an expandable cage for three-column uncomplicated subaxial type «B» injures: a multicenter retrospective study

Vadim A. Byvaltsev[1,2,3] · Andrei A. Kalinin[1,2] · Evgenii G. Belykh[4] · Marat A. Aliyev[5,6] · Bair B. Sanzhin[1] · Alexander V. Kukharev[1] · Yermek K. Dyussembekov[5] · Valerii V. Shepelev[1,7] · K. Daniel Riew[8,9]

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Abstract

Purpose To evaluate the clinical and radiological results of the operative management of three-column uncomplicated type «B» subaxial injures treated with a one-level cervical corpectomy with an expandable cage.

Methods This study included 72 patients with a three-column uncomplicated type «B» subaxial injures who met the inclusion criteria, underwent a one-level cervical corpectomy with an expandable cage at one of three neurosurgical departments between 2005 and 2020, and were followed up for clinical and radiological outcomes at a minimum 3-yr follow-up.

Results There was a decrease in the VAS pain score from an average of 80 mm to 7 mm ($p=0.03$); a decrease in the average NDI score from 62 to 14% ($p=0.01$); excellent and good outcomes according to Macnab's scale were 93% (n = 67/72). There was an average change in the cervical lordosis (Cobb method) from −9.10 to −15.40 ($p=0.007$), without significant loss of lordosis ($p=0.27$). There was no significant degeneration of the adjacent levels by 3 years post-op. The fusion rate, using the Cervical Spine Research Society criteria, was poor: it was 62.5% (n = 45/72), and using the CT criteria, it was 65.3% (n = 47/72). 15.4% patients (n = 11/72) suffered complications. Statistical difference between the fusion and pseudoarthrosis (according to X-ray criteria) subgroups showed that there were no statistically significant differences in the smoking status, diabetes, chronic steroid use, cervical injury level, subtypes of AO type B subaxial injuries and types of expandable cage systems.

Conclusions One-level cervical corpectomy with an expandable cage, despite a poor fusion rate, can be considered a feasible and relatively safe method for treating three-column uncomplicated subaxial type «B» injures, with the benefit of immediate stability, anatomical reduction, and direct decompression of the spinal cord. While no one in our series had any catastrophic complications, we did note a high complication rate.

Keywords Cervical spine · Uncomplicated three-column subaxial type «B» injures · Ventral decompression · Corpectomy · Transbody fusion · Telescopic prostheses

Introduction

Cervical spine injury can have substantial societal impact due to its frequent occurrence in people of working age [1]. The degree of restoration of the functional state, quality of life and social rehabilitation depend on timely diagnosis and appropriate treatment [2, 3]. One of the more common cervical injuries is the AO Spine [4] type "B" subaxial cervical spine fracture, which is characterized by disruption of the anterior, middle, and posterior support columns by a distraction/compression mechanism [5]. Uncomplicated three-column type "B" subaxial injures require restoration and stabilization of the anterior and posterior columns, correction of the traumatic deformity, and a thorough decompression of the neural structures [6].

In most cases, there is no injury to the anterior tension band in type B fractures, and therefore the use of ventral decompression and stabilization is controversial [7]. Ventral compression of the spinal cord by bony fragments or a traumatic intervertebral disc (IVD) herniation is usually best treated anteriorly with a corpectomy and ventral fixation [8].

✉ Vadim A. Byvaltsev
byval75vadim@yandex.ru

Extended author information available on the last page of the article

On the other hand, a posterior approach may be advantageous when the posterior tension band needs to be restored without the need for anterior decompression or anterior column support, especially in someone with premorbid stenosis [9]. Finally, some injuries may be best treated with a combined anterior–posterior approach, which is associated with greater surgical trauma and risks of neurological deficit when changing the position of the patient on the operating table [8]. Thus, the optimal surgical treatment of unstable three-column uncomplicated type "B" subaxial injures, with clinical signs of ventral compression of neural structures, has not been established. To our knowledge there are no large, multicenter studies with long-term follow-up of unstable three-column type "B" subaxial injures treated with a corpectomy and reconstructed with a telescoping prosthesis [10–12]. The lack of such information was the basis for this study.

Objective–to evaluate the clinical and radiological results of three-column uncomplicated subaxial type «B» injures treated with a one-level cervical corpectomy with an expandable cage.

Methods

Study design

A retrospective study was conducted in 2334 patients operated on the cervical spine for traumatic injuries in 3 neurosurgical units (*Blinded*) from January 2005 to January 2020. In the study group, there were 3 main surgeons, with more than 15 years of experience of cervical spine surgery at 2005 year. All patients were in a rigid collar post-operatively.

The medical records of patients who underwent anterior decompression and stabilization using a single-level corpectomy reconstructed with a telescoping prosthesis for three-column uncomplicated type "B" subaxial injures were analyzed: B1 type (pure transosseous disruption) n = 29 (40.3%), B2 type (osteo-ligamentous disruption) n = 32 (44.4%) and B3 type (hyperextension) n = 11 (15.3%).

In total, 72 patients met the inclusion criteria, were available for analysis at long-term follow-up, and had a full set of X-rays, MRI and CT. Written consent was obtained in each case. The study protocol was approved by the ethics committee of (*Blinded*). The analysis was carried out in accordance with the principles of the Declaration of Helsinki. The design of the study is presented in Fig. 1.

Inclusion criteria

The study included patients with:

1. Subaxial injury between C3–C7;
2. Single-level Subaxial Injury Classification (SLIC) scale 6–8 points [13], distraction AO Spine type "B" [4];
3. American Spinal Injury Association (ASIA) E severity and International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) [14];
4. Presence of ventral compression of nerve structures by a post-traumatic disc herniation or damaged vertebral body fragment with clinical manifestations of radicular pain, motor or sensory neurological deficits;
5. Absence of MRI signs of cord trauma;
6. No unilateral or bilateral facet subluxation;
7. Hospitalization and surgery within 72 h of injury.

Exclusion criteria

The criteria for exclusion from the study were:

1. Multilevel subaxial injury;
2. Osteoporotic fracture (T-criterion value −2.5 SD and below by Dual Energy X-ray Absorbtiometry);
3. Cervical spinal stenosis prior to the injury;
4. Complicated type "B" distraction injury–A-D injury severity (ASIA/ISNCSCI) [14];
5. AO Spine subaxial injury types "A" and "C" [4];
6. Delay between injury and treatment;
7. The presence of comorbid diseases (uncontrolled or decompensated medical conditions, which were a contraindication to anesthesia and surgery).

Study conditions

All operations were performed under general anesthesia with Mayfield tong (USA) fixation. Caspar distraction (Germany), an operating microscope, intraoperative fluoroscopy (Siemens, Germany) and intraoperative neurophysiological monitoring ISIS (Inomed, Germany) were used. A left-sided approach was used. The posterior longitudinal ligament was not resected. An ADD-plus expandable cage (Urlich, Germany, no conflicts by authors) with screw fixation and a Tecorp expandable cage (Alphatec Spine, USA, no conflicts by authors) with anterior plate were placed. The expandable cage does not allow for the use of bone grafts. Also, we did not place graft material outside of the cage. Post-operatively, all patients wore compression stockings and ambulated within 1–2 days. Follow-up was a minimum of 3 years.

Study data

- *General information* demographics (gender, age, BMI, ASA), duration of surgery, EBL and postoperative course.
- *Clinical outcomes* VAS neck pain score; Neck Disability Index (NDI); Macnab scale; complications.

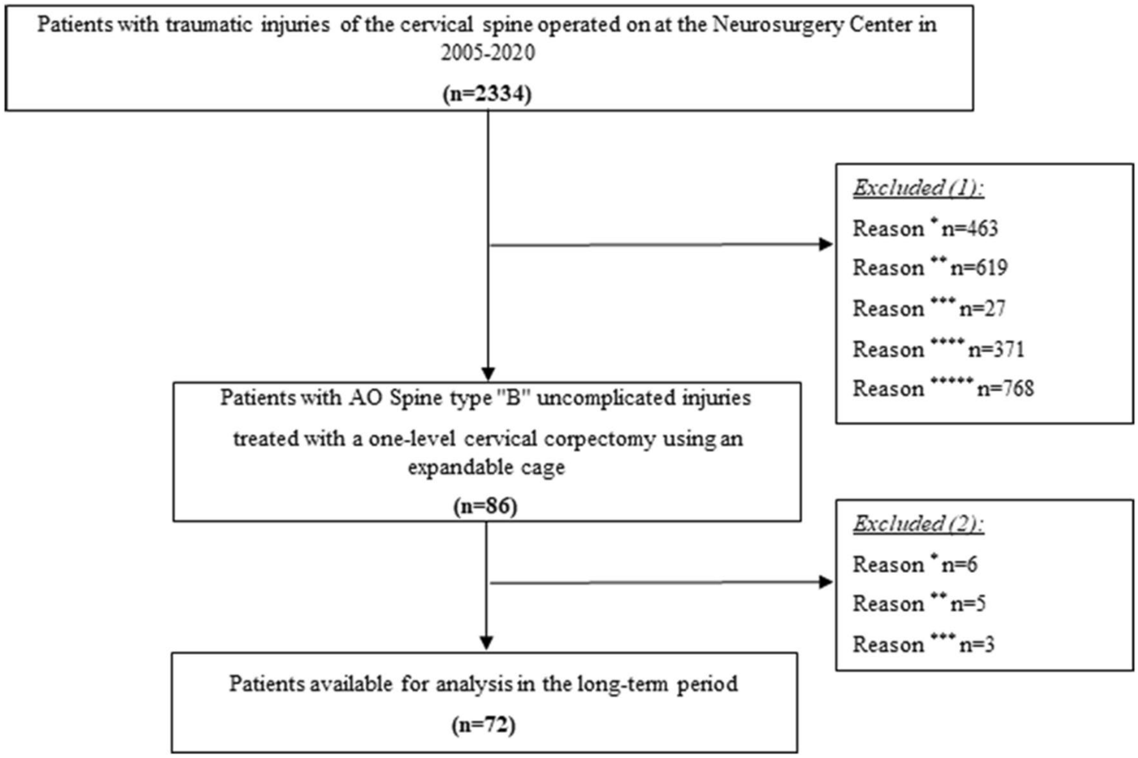


Fig. 1 Patients' study flowchart. *Exclude reason (1):* Reason *—injury C1-C2 localization; Reason **—Type A subaxial injury; Reason ***—complicated Type B subaxial injury; Reason ****—Type C subaxial injury; Reason *****—multilevel subaxial injury; *Exclude reason (2):* Reason *—loss of follow-up; Reason **—refusal to participate in the study; Reason ***—death unrelated to the operation (in these cases, there were no postoperative complications)

- *Radiographic outcomes* sagittal Cobb angles; adjacent IVD degeneration (Pfirrmann C. classification) [15], adjacent facet joint (FJ) degeneration (Fujiwara A. classification) [16]; fusion assessment using Cervical Spine Research Society (CSRS) criteria [17]: (1) inter-spinous processes motion < 1 mm on 150% magnified flection-extension X-rays with > 4 mm of motion at an adjacent non-operated level or (2) the presence of bridging bone across the graft into adjacent endplates and bridging bone outside of the graft or cage and no lucent lines (defined as radiolucent line extending > 50% of the cortical-host bone interface) according to CT scans. The radiographs and CT were evaluated by two independent, blinded and uninvolved experts (neurosurgeon and radiologist). The expert agreement was assessed using Kappa statistics (Graph Pad Software, Inc., USA).

Statistical analysis

Statistical data were obtained using the Statistica-8 database processing program. The distribution pattern was based on the Shapiro–Wilk, Kolmogorov–Smirnov and Liljefors tests. Taking into account the presence of significant differences according to these tests ($p < 0.05$), the distribution was considered to be different from the normal, in connection with which the assessment of the significance of the differences in the sample sets was made according to the criteria of nonparametric statistics: the Mann–Whitney (MW) test for intergroup comparison, Wilcoxon criterion for dependent samples, and Fisher's exact test for binomial parameters. Differences were considered significant at $p < 0.05$. The data were presented as the median, the values of the 1st and 3rd quartiles—Me (Q25; Q75).

Results

Of the 2334 patients with traumatic cervical injuries, 72 met the study criteria (Table 1). Middle-aged males, C5 (29.2%) and C6 (36.1%) injuries, types B1 (40.3%) and B2 (44.4%), and traffic accidents (59.7%) were most common. In 20 patients (27.8%), the concomitant type of injury was verified. The majority of patients (56.9%) were ASA II. Follow-up was 70 months (40;82).

The operation duration was 155 (120–215) minutes, estimated blood loss (EBL) was 285 (235—350) ml, and the hospital length-of-stay was 8 (6–9) days.

Table 1 General information and preoperative data in the study group

Criterion	Study group ($n=72$)
Age (years), Me (Q_{25}; Q_{75})	34 (25;44)
Gender	
Male, *n* (%)	49 (68.1)
Female, *n* (%)	23 (31.9)
Cervical injury level	
C3, *n* (%)	5 (6.9)
C4, *n* (%)	9 (12.5)
C5, *n* (%)	21 (29.2)
C6, *n* (%)	26 (36.1)
C7, *n* (%)	11 (15.3)
Mechanism of cervical spine injury	
Traffic accident, *n* (%)	43 (59.7)
Diving injury, *n* (%)	18 (25)
Fall from height, *n* (%)	11 (15.3)
Concomitant injury	
Brain concussion, *n* (%)	8 (11.1)
Chest injury, *n* (%)	5 (6.9)
Upper limb fracture, *n* (%)	2 (2.8)
Lower limb fracture, *n* (%)	3 (4.2)
Skin burns	2 (2.8)
Type of injury	
B1, *n* (%)	29 (40.3)
B2, *n* (%)	32 (44.4)
B3, *n* (%)	11 (15.3)
Radicular symptoms	
Pain, *n* (%)	23 (31.9)
Sensory deficit, *n* (%)	9 (12.5)
Muscle weakness, *n* (%)	2 (2.8)
Physical status by ASA, n (%)	
I	12 (16.7)
II	41 (56.9)
III	15 (20.8)
IV	4 (5.6)
Smoking status, *n, %*	39 (54.2)
Diabetes, *n, %*	7 (9.7)
Chronic steroid use, *n, %*	3 (4.2)

In all cases, after the operation, we noted a complete resolution of the radicular symptoms.

VAS pain scores decreased from 80 mm (72–87) to 17.5 mm (14–21) at discharge ($p<0{,}001$) and to 8.5 mm (4–17) at final follow-up ($p=0.03$) (Fig. 2).

Final follow-up NDI scores were: 47 patients (65.3%) had no disability, 21 (29.2%) had mild, 4 (5.5%) had moderate and none had severe disability. Mean pre-operative NDI was 62% (54–78), which decreased by discharge to 32% (18–40) ($p=0.03$) and to 14% (6–20) by final follow-up ($p=0.01$).

At final follow-up, Macnab patient satisfaction scale was: excellent—44 (61.1%); good–23 (31.9%); satisfactory—5 (7%); no unsatisfactory outcomes.

Complications are presented in Table 2. There were two cases of transient dysphagia and one transient dysphonia post-op. Two had retropharyngeal hematomas requiring surgical drainage without further complications. One had a superficial infection that resolved with local antiseptics and antibiotics. One with symptomatic adjacent segment pathology underwent anterior cervical discectomy and fusion (ACDF). None of the above were felt to be directly related to the cage. Three with severe postoperative neck pain without neurologic deficits were treated with laser FJ denervation. In one, there was minimal screw back out without instability or other complications. Of the 11 complications, only 6 patients were verified (a combination of identified complications was detected), which accounted for 8.3% of cases.

Inter-observer agreement (Kappa) was excellent for C2–C7 lordotic Cobb angles 0.908 ± 0.072 (0.800–1.000, 95% CI), for the adjacent levels by Pfirrmann C. IVD classification 0.916 ± 0.073 (0.844–1.000, 95% CI) and Fujiwara A. FJ classification 0.903 ± 0.037 (0.852–1.000, 95% CI), for interspinous process motion on dynamic radiographs 0.889 ± 0.014 (0.814–1.000, 95% CI) and CT bridging bone 0.961 ± 0.004 (0.936–1.000, 95% CI).

The C2–C7 lordotic Cobb angles significantly increased post-operatively from -9.1^0 (−5.7–12.7) to -15.4^0 (−13.1;−17.2) at long-term follow-up ($p=0.007$) without significant loss of alignment throughout the follow-up period ($p=0.27$).

There was no significant degeneration of the adjacent levels using Pfirrmann C. IVD classification and Fujiwara A. FJ classifications ($p=0.12$ and $p=0.67$, respectively).

The fusion rate was low at ≥ 36-month follow-up. Using X-ray criteria, it was 62.5% (n = 45), and using CT criteria, it was 65.3% (n = 47). Of note, initial fusion rate using Bridwell criteria was 90.3% (n = 65). There were no cases of symptomatic pseudoarthrosis. All laminar fractures healed.

Comparison between the fusion and pseudoarthrosis (according to X-ray criteria) subgroups (Table 3) showed that there were no statistically significant differences in the smoking status, diabetes, chronic steroid use, cervical injury level, subtypes of AO type B subaxial injuries and types of expandable cage systems ($p>0{,}05$).

Figure 3 [18] and Fig. 4 are of a representative case.

Discussion

There are conflicting opinions about the optimal method of surgical treatment of three-column uncomplicated AO Spine type "B" subaxial injures [13]. It has been reported that the best biomechanical stability in cases of three-column

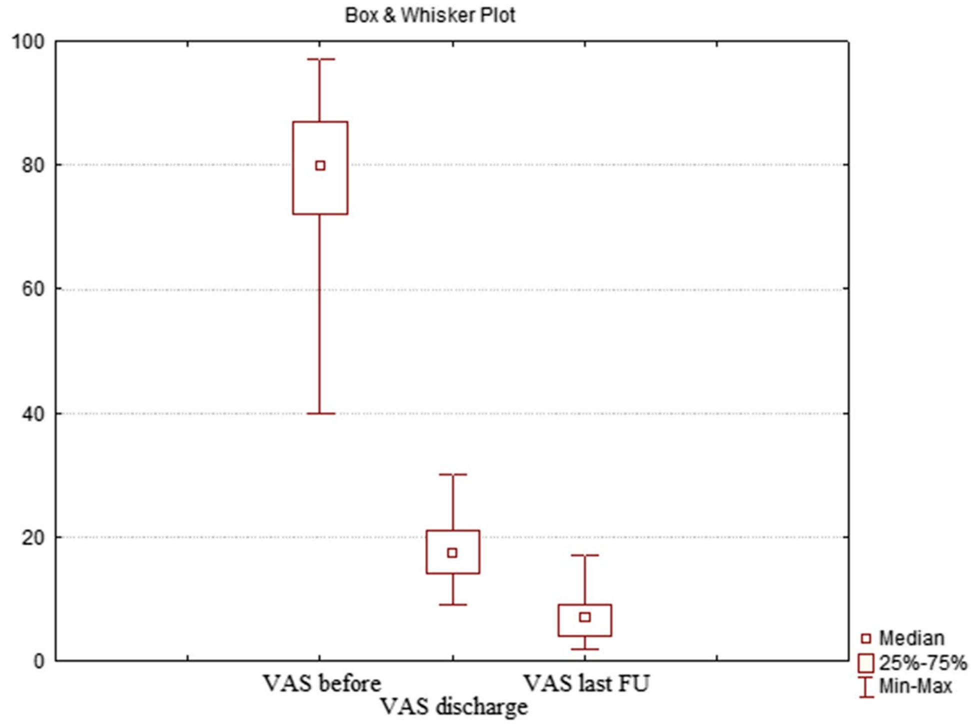


Fig. 2 Change in the VAS neck pain score post-operatively

Table 2 Reported complications in the study group (excluding pseudarthrosis)

Complication type	Count	Frequency in the study sample (%)	Frequency among complications (%)
Perioperative	6	8.4	54.6
Postoperative transient dysphagia	2	2.8	18.2
Postoperative hematoma formation	2	2.8	18.2
Postoperative transient dysphonia	1	1.4	9.1
Surgical site infection	1	1.4	9.1
Delayed	5	7	45.4
Clinically significant facet syndrome in the operated segment (local neck pain, topically coinciding with the level of corpectomy)	3	4.2	27.2
Symptomatic degeneration of the adjacent level	1	1.4	9.1
Minimal screw back out	1	1.4	9.1
Total	11	15.4	100

subaxial injuries is achieved with a combined (anterior and posterior) surgical approach [19]. While no one can argue that the circumferential approach results in maximal stabilization, it has been our experience that a single-level corpectomy reconstructed with a telescopic prosthesis for three-column uncomplicated type “B” subaxial injures can result in adequate stability with good clinical results. Since the vast majority of the neural compression is anterior, one can decompress and stabilize with a unilateral approach that is less invasive than a circumferential procedure.

We found that there was statistically significant decrease in the severity of pain as measured by VAS pain scores at baseline to final follow-up. Likewise, the NDI scores improved such that 65.3% had no disability, 29.2% had mild disability, 5.5% had moderate disability and none had severe disability. At the final follow-up, patient satisfaction according to the Macnab scale was: excellent in 61.1%, good in 31.9%, satisfactory in 7%, with no unsatisfactory outcomes. There were no complications that were felt to be directly related to the cage. The C2–C7 lordotic Cobb angles significantly increased post-operatively from -9.1^0 (−5.7;−12.7) to -15.4^0 (−13.1;−17.2) at long-term follow-up ($p=0.007$) without significant loss of alignment throughout the follow-up period ($p=0.27$). The fusion rate was low at a minimum

36-month follow-up. Using the X-ray criteria, it was 62.5% (n = 45), and using the CT criteria, it was 65.3% (n = 47). However, there were no cases of symptomatic pseudoarthrosis. In all cases, a complete consolidation of the vertebral lamina injury was verified.

Choice of surgical approach

In 2007, Dvorak MF et al. proposed an algorithm for selecting the approach to the subaxial spine based on a systematic review of 26 I–III level-of-evidence publications [13]. According to the authors, combined 360-degree surgery was felt to be optimal for surgical treatment of patients with distraction types of injuries in the presence of subluxation of the FJ; in the absence of traumatic dislocation of the FJ, an anterior decompressive-stabilizing intervention was felt to be possible.

Yoon JW et al. described the advantages of reconstructing a corpectomy defect with a telescoping prostheses for three-column subaxial injuries, since this type of implant, due to the distraction expanding mechanism, makes it less likely to migrate into the spinal canal [20].

Considering the presence of traumatic IVD herniation in more than 20% of patients with subaxial trauma [21, 22], in the absence of FJ subluxation, in our opinion, the anterior approach using corpectomy allows for direct ventral decompression of the spinal cord. At the same time, the use of a telescoping prosthesis makes it possible to restore cervical lordosis by distraction, as well as to perform effective stabilization of the damaged segment via a unilateral surgical approach.

Clinical outcomes

Corpectomy has been shown to be effective treatment for three-column subaxial injuries. In a prospective clinical series, Madan A et al. presented the results of one two and three level corpectomy with Mesh-type implants and an anterior cervical plate in patients with three-column subaxial injuries [10]. Post-operatively, NDI results were as follows: 27.3% had outcomes without restrictions, 62.6% had mild restrictions, 6.1% had moderate restrictions and 4.0% had severe restrictions. Sonawane D et al. reported on 8 patients with unstable three-column type "B" injures treated with anterior corpectomy, autologous bone and anterior cervical plate fixation [12]. Post-operatively, there was a significant decrease in pain VAS from 4.75 to 1.75 cm; improvement in functional state according to NDI (average decrease from 25 to 11.5); improvement in the ASIA scale in 7 patients (87.5%). We also found significant improvement in pain and NDI scores at a minimum 3-year follow-up. Our results are likely positively impacted by the fact that we included only patients with uncomplicated injuries of the subaxial spine who were operated within 72 h of injury.

Radiological outcomes

The use of telescoping implants in the cervical spine is not without drawbacks. Byvaltsev VA et al. studied a cohort of patients (n = 78) who underwent corpectomy and reconstruction with telescoping cages for cervical stenosis and found good clinical outcomes at 2-year minimum follow-up but with a low incidence of fusion (about 50% according to

Table 3 Comparison of the fusion and pseudoarthrosis subgroups

Factor	Pseudoarthrosis subgroup (n = 45)	Fusion subgroup (n = 27)	*p* value
Smoking status, *n, %*	26 (57.8)	13 (48.1)	0.41
Diabetes, *n, %*	5 (11.1)	3 (11.1)	0.63
Chronic steroid use, *n, %*	2 (4.4)	1 (3.7)	0.68
Cervical injury level			
C3, *n* (%)	3 (6.7)	2 (7.4)	0.57
C4, *n* (%)	6 (13.3)	3 (11.1)	
C5, *n* (%)	13 (28.9)	8 (29.6)	
C6, *n* (%)	16 (35.6)	10 (37.1)	
C7, *n* (%)	7 (15.5)	4 (14.8)	
Type of injury			
B1, *n* (%)	18 (40)	11 (40,8)	0.39
B2, *n* (%)	19 (42.2)	13 (48.1)	
B3, *n* (%)	8 (17.8)	3 (11.1)	
Type of expandable cage system			
ADD-plus (Urlich), *n* (%)	28 (62.2)	15 (55.6)	0.46
Tecorp (Alphatec Spine), *n* (%)	17 (37.8)	12 (44.4)	

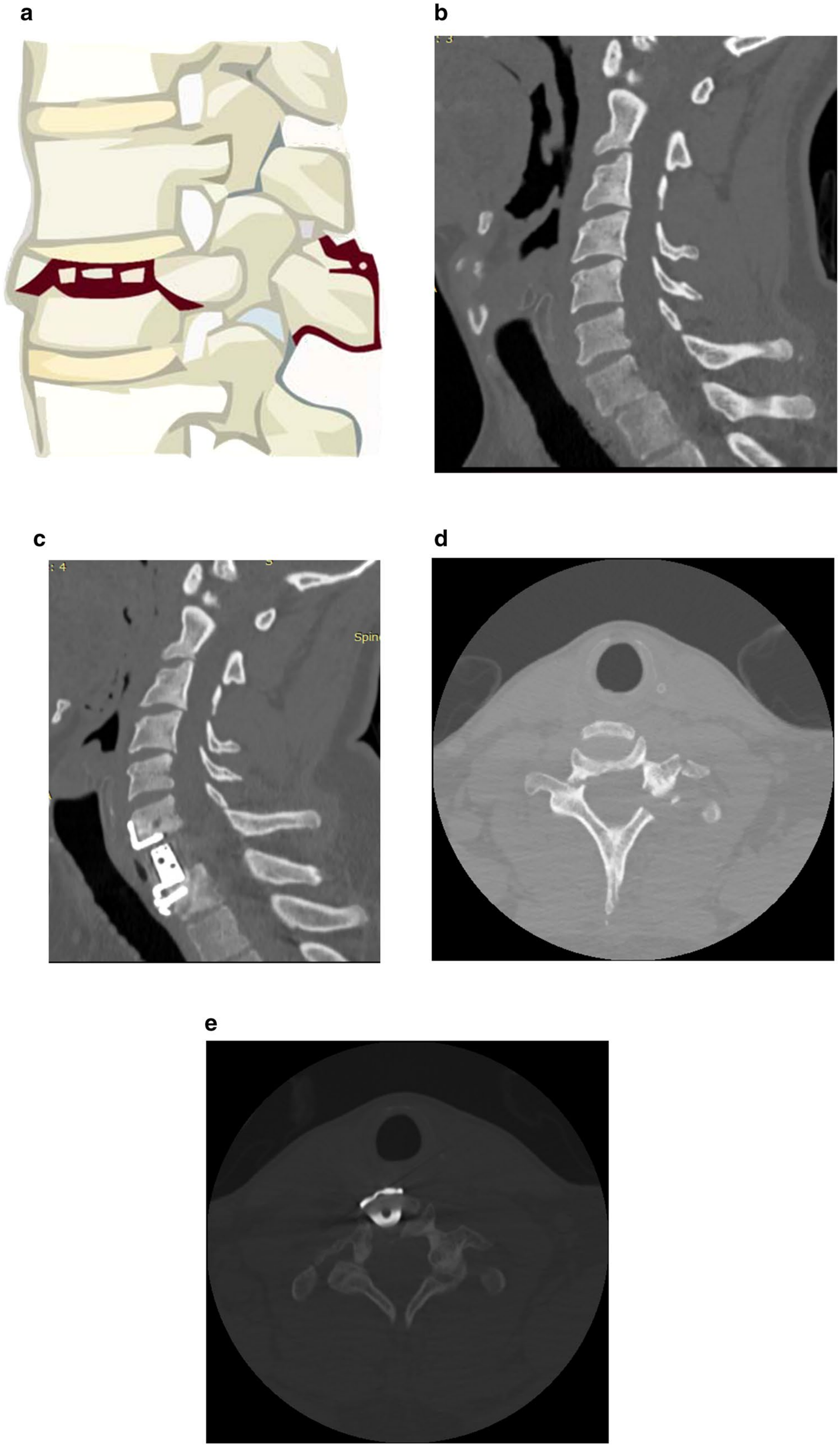
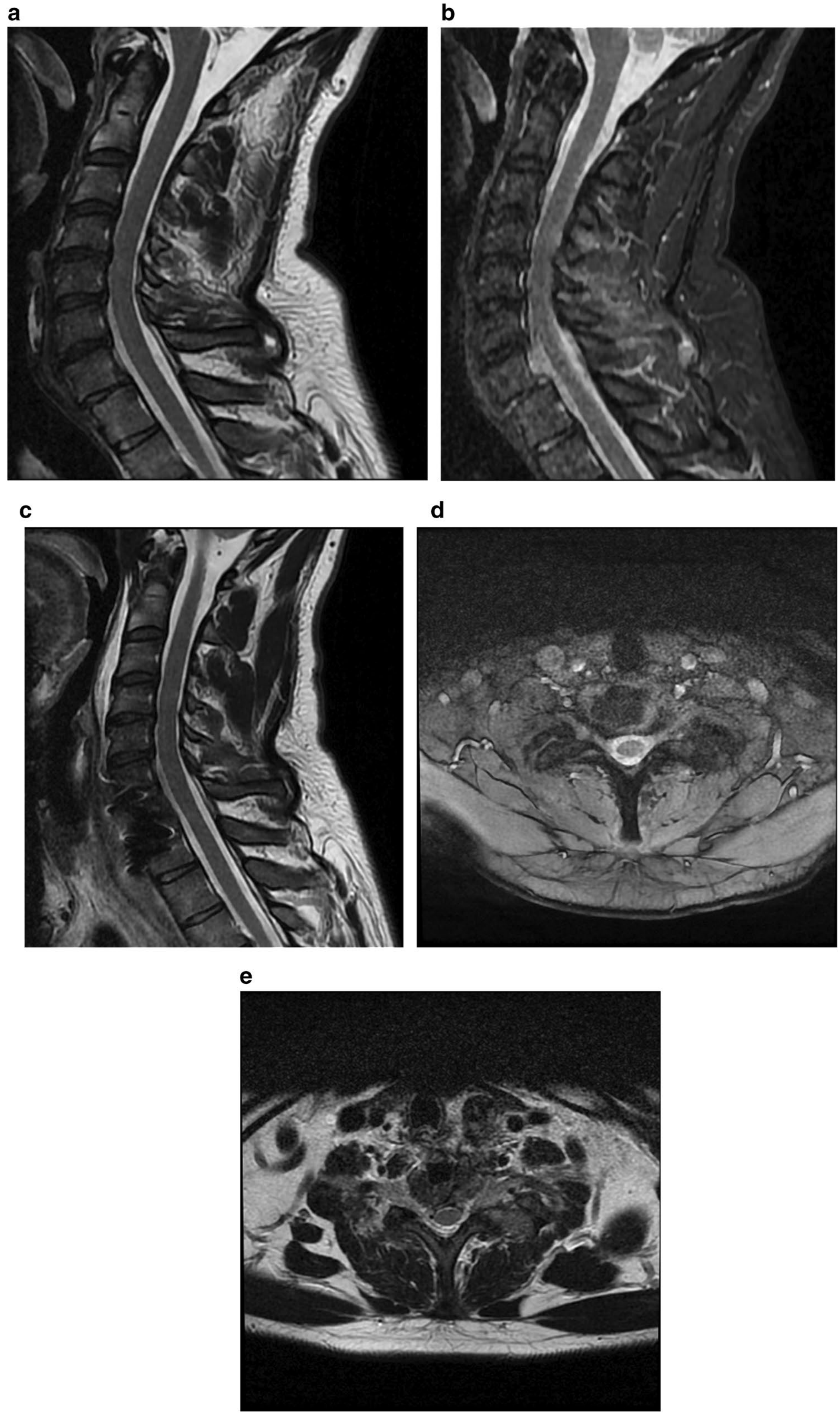


Fig. 3 Patient E.: **a** schematic image [18]; **b** sagittal image showing C7 fracture; **c** sagittal projection after C7 corpectomy with expandable cage implantation; **d** axial image before surgery at C7–B2 injury: complete disruption of the posterior bony capsuloligamentous structures together with a vertebral body, disc, and left side facet joint injury without facet subluxation; e axial image at the level of the C7 corpectomy. Note the healing of the posterior column laminar fracture

Fig. 4 MRI of patient E.: **a** sagittal projection before surgery T2 weighted image; **b** sagittal image before surgery T2 weighted image STIR–complete disruption of the posterior capsuloligamentous structures (indicated by arrow); **c** sagittal projection after C7 corpectomy with expandable cage implantation; **d** axial image at C7-Th1; e post-operative axial image at C7-Th1, without neural compression



strict CSRS criteria) [23]. We also noted a low fusion rate. Using the X-ray criteria, it was 62.5% (n = 45), and using the CT criteria, it was 65.3% (n = 47), with no cases of implant subsidence. However, there were no cases of symptomatic pseudoarthrosis.

Other reports regarding the use of telescoping cages all noted a high fusion rate. Elder BD et al. noted a higher percentage of fusion (79–100%) in the period from 9 to 41 months demonstrating a fairly frequent implant subsidence of 0–43% [24]. Pojskic's series of 86 corpectomy patients reconstructed with telescoping cages for various pathologies (spinal canal stenosis, spondylodiscitis, metastatic lesion, and traumatic injuries) noted a fusion rate of 86%, with implant subsidence 20 (24.4%) cases [25]. Madan A et al. reported that according to Bridwell criteria, Grade I fusion was registered in 64 patients (64.6%), Grade II–in 31 patients (31.3%), Grade III–in 4 patients (4.0%) [10]. It should be noted, however, that none of the above studies used fusion criteria as stringent as ours. We used criteria that is recommended by the CSRS and that has been demonstrated to be the most accurate, compared to surgical exploration. In fact, when we originally used the Bridwell criteria, we found that 90.3% (n = 65) were fused. It is obvious that the less stringent and less accurate the fusion criteria, the higher the fusion rate.

Complications

In a retrospective study by Tasiou A et al., perioperative complications were observed in 15 cases (12.28%) out of 114 patients: dural tear (n = 2), dysphagia (n = 2), clinical deterioration (n = 1), recurrent nerve injury (n = 1), soft tissue edema (n = 2), esophageal perforation (n = 1), surgical site infection (n = 1), implant migration (n = 1), adjacent segment degeneration (n = 3), and tracheoesophageal fistula formation (n = 1) [26]. In a systematic review, Elder BD et al. pointed to possible causes of the adjacent segment degenerative disease: the presence of osteoporosis, placement of the implant without a close fit to the endplate over the entire surface, excessive segmental distraction when extending the prosthesis [25]. Our results were roughly in line with that in the literature: in our series, the number of adverse surgical outcomes was 15.4% (n = 11).

Study limitations and strengths

Our study's limitations include the following. First, it is retrospective. Second, we used two types of implants without their comparative analysis. Therefore, our results may not be generalizable to other constructs. Third, our results cannot be extrapolated to what might happen with multi-level injuries. Finally, we did not have controls.

Despite the above limitations and recent studies with large sample sizes, multilevel lesions, and different surgical approaches to the treatment of subaxial spinal injuries [27, 28], this study has a number of strengths. First, it has one of the longest follow-up periods: the minimum follow-up was 3 years, the average was 70 months (40;82). Second, the study included the largest series of cases of using telescoping prostheses for uncomplicated type "B" injuries of the subaxial—72 cases available for analysis at long-term follow-up. Thirdly, we have a full set of clinical data (VAS, NDI, Macnab). Finally, we utilized radiological criteria demonstrated to be the most accurate one and approved by the CSRS, a first for these types of constructs evaluated in a large case series. We found that the fusion rate was quite low, in contrast to previous reports using telescoping cages. But this is also the first paper, to our knowledge, that utilized the CSRS accepted criteria for assessing fusions.

Conclusions

The prevalence of AO Spine type "B" traumatic injuries was 4.8% (113 of 2334), of which uncomplicated injury was verified in 3.7% (86 of 2334).

A multicenter retrospective analysis of the outcomes of surgical treatment of 72 patients with AO Spine type "B" uncomplicated subaxial injuries without subluxation of the FJ between C4–C7 confirmed the long-term clinical efficacy of single-level corpectomy reconstructed with a telescoping prostheses. There was a significant reduction in the post-operative cervical spine VAS pain score from 80 mm (72;87) to 7 mm (4;9) ($p < 0.05$), improvement in the NDI patient reported outcome measure from 62% (54;78) to 14% (6;20) ($p < 0.05$), as well as a high degree of patient satisfaction with the surgery on the Macnab scale; excellent and good outcomes were 93%.

Radiographically, there was effective restoration of the cervical lordosis from -9.1^0 (−5.7; −12.7) to -15.4^0 (−13.1; −17.2) ($p = 0.007$) without significant loss in the long-term period ($p = 0.27$). On the other hand, there was a high pseudarthrosis rate (CSRS plain radiographic criteria) of 62.5% (n = 45), and using the CT criteria, it was 65.3% (n = 47). Despite this, there were no symptomatic pseudarthrosis cases requiring revision and overall, there was a low number of long-term perioperative complications—5 (6.9%). We did not find a statistical difference between the subgroups of patients with fusion and pseudarthrosis, depending on the well-known risk factors for impaired fusion formation.

Authors contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [VAB], [AAK], [EGB], [MAA], [BBS], [AVK], [YKD] and [VVS]. The first draft of the manuscript was written by [VAB], [AAK] and [KDR] and then all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declarations

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

References

1. Witiw CD, Fehlings MG (2015) Acute spinal cord injury. J Spinal Disord Tech 28(6):202–210. https://doi.org/10.1097/BSD.0000000000000287
2. Grassner L, Wutte C, Klein B, Mach O, Riesner S, Panzer S, Vogel M, Bühren V, Strowitzki M, Vastmans J, Maier D (2016) Early decompression (< 8 h) after traumatic cervical spinal cord injury improves functional outcome as assessed by spinal cord independence measure after one year. J Neurotrauma 33(18):1658–1666. https://doi.org/10.1089/neu.2015.4325
3. Wilson JR, Vaccaro A, Harrop JS, Aarabi B, Shaffrey C, Dvorak M, Fisher C, Arnold P, Massicotte EM, Lewis S, Rampersaud R, Okonkwo DO, Fehlings MG (2013) The impact of facet dislocation on clinical outcomes after cervical spinal cord injury: results of a multicenter North American prospective cohort study. Spine (Phila Pa 1976) 38(2):97–103. https://doi.org/10.1097/BRS.0b013e31826e2b91
4. Vaccaro AR, Koerner JD, Radcliff KE, Oner FC, Reinhold M, Schnake KJ, Kandziora F, Fehlings MG, Dvorak MF, Aarabi B, Rajasekaran S, Schroeder GD, Kepler CK, Vialle LR (2016) AOSpine subaxial cervical spine injury classification system. Eur Spine J 25(7):2173–2184. https://doi.org/10.1007/s00586-015-3831-3
5. Divi SN, Schroeder GD, Oner FC, Kandziora F, Schnake KJ, Dvorak MF, Benneker LM, Chapman JR, Vaccaro AR (2019) AOSpine-spine trauma classification system: the value of modifiers: a narrative review with commentary on evolving descriptive principles. Global Spine J 9(1 Suppl):77S-88S. https://doi.org/10.1177/2192568219827260
6. Joaquim AF, Lee NJ, Riew KD (2021) Circumferential operations of the cervical spine. Neurospine 18(1):55–66. https://doi.org/10.14245/ns.2040528.264
7. Sethy SS, Ahuja K, Ifthekar S, Sarkar B, Kandwal P (2021) Is anterior-only fixation adequate for three-column injuries of the cervical spine? Asian Spine J 15(1):72–80. https://doi.org/10.3161/asj.2019.0225
8. Wu HH, Tang T, Yu X, Pang QJ (2018) Stability of two anterior fixations for three-column injury in the lower cervical spine: biomechanical evaluation of anterior pedicle screw-plate fixation. J Int Med Res 46(4):1455–1460. https://doi.org/10.1177/0300060517734687
9. Yang JS, Liu JJ, Liu P, Zhang ZX, Liu TJ, Tuo Y, Yan L, Zhang ZP, Zhang HP, Chen H, Hao DJ (2020) Can posterior ligament structure be functionally healed after anterior reduction and fusion surgery in patients with traumatic subaxial cervical fracture-dislocations? World Neurosurg 134:e243–e248. https://doi.org/10.1016/j.wneu.2019.10.045
10. Madan A, Thakur M, Sud S, Jain V, Singh Thakur RP, Negi V (2019) Subaxial cervical spine injuries: outcomes after anterior corpectomy and instrumentation. Asian J Neurosurg 14(3):843–847. https://doi.org/10.4103/ajns.AJNS_331_17
11. Abdelgawaad AS, Metry ABS, Elnady B, El Sheriff E (2021) Anterior cervical reduction decompression fusion with plating for management of traumatic subaxial cervical spine dislocations. Global Spine J 11(3):312–320. https://doi.org/10.1177/2192568220903741
12. Sonawane D, Dave H, Savant S, Garg B, Bangalore S, Chandanwale A (2021) Cervical corpectomy in delayed presentation of irreducible cervical dislocation: experience with eight cases. Br J Neurosurg. https://doi.org/10.1080/02688697.2021.1885619
13. Dvorak MF, Fisher CG, Fehlings MG, Rampersaud YR, Oner FC, Aarabi B, Vaccaro AR (2007) The surgical approach to subaxial cervical spine injuries: an evidence-based algorithm based on the SLIC classification system. Spine (Phila Pa 1976) 32(23):2620–2629. https://doi.org/10.1097/BRS.0b013e318158ce16
14. Kirshblum S, Snider B, Rupp R, Read MS; International Standards Committee of ASIA and ISCoS (2020) Updates of the international standards for neurologic classification of spinal cord injury: 2015 and 2019. Phys Med Rehabil Clin N Am 31(3):319–330. https://doi.org/10.1016/j.pmr.2020.03.005
15. Pfirrmann CW, Metzdorf A, Zanetti M, Hodler J, Boos N (2001) Magnetic resonance classification of lumbar intervertebral disc degeneration. Spine (Phila Pa 1976) 26(17):1873–1878. https://doi.org/10.1097/00007632-200109010-00011
16. Fujiwara A, Lim TH, An HS, Tanaka N, Jeon CH, Andersson GB, Haughton VM (2000) The effect of disc degeneration and facet joint osteoarthritis on the segmental flexibility of the lumbar spine. Spine (Phila Pa 1976) 25(23):3036–3044. https://doi.org/10.1097/00007632-200012010-00011
17. Rhee JM, Chapman JR, Norvell DC, Smith J, Sherry NA, Riew KD (2015) Radiological determination of postoperative cervical fusion: a systematic review. Spine (Phila Pa 1976) 40(13):974–991. https://doi.org/10.1097/BRS.0000000000000940
18. Vu C, Gendelberg D (2020) Classifications in brief: AO thoracolumbar classification system. Clin Orthop Relat Res 478(2):434–440. https://doi.org/10.1097/CORR.0000000000001086
19. Lee DY, Park YJ, Song MG, Kim KT, Kim DH (2021) Comparison of anterior-only versus combined anterior and posterior fusion for unstable subaxial cervical injuries: a meta-analysis of biomechanical and clinical studies. Eur Spine J 30(6):1460–1473. https://doi.org/10.1007/s00586-020-06704-0
20. Yoon JW, Tavanaiepour K, Tyler A, Keshavarzi S (2016) Management of severe traumatic flexion-distraction injuries in a multisystem trauma patient: a case report. Trauma Case Rep 5:18–23. https://doi.org/10.1016/j.tcr.2016.09.009
21. Ren C, Qin R, Wang P, Wang P (2020) Comparison of anterior and posterior approaches for treatment of traumatic cervical dislocation combined with spinal cord injury: minimum 10-year follow-up. Sci Rep 10(1):10346. https://doi.org/10.1038/s41598-020-67265-2
22. Rizzolo SJ, Piazza MR, Cotler JM, Balderston RA, Schaefer D, Flanders A (1991) Intervertebral disc injury complicating cervical spine trauma. Spine (Phila Pa 1976) 16(6 Suppl):S187–S189. https://doi.org/10.1097/00007632-199106001-00002
23. Byvaltsev VA, Kalinin AA, Aliyev MA, Azhibekov NO, Shepelev VV, Riew KD (2021) Poor fusion rates following cervical corpectomy reconstructed with an expandable cage: minimum 2-year radiographic and clinical outcomes. Neurosurgery 89(4):617–625. https://doi.org/10.1093/neuros/nyab240
24. Elder BD, Lo SF, Kosztowski TA, Goodwin CR, Lina IA, Locke JE, Witham TF (2016) A systematic review of the use of expandable cages in the cervical spine. Neurosurg Rev 39(1):1–11. https://doi.org/10.1007/s10143-015-0649-8

25. Pojskic M, Saβ B, Nimsky C, Carl B (2020) Application of an expandable cage for reconstruction of the cervical spine in a consecutive series of eighty-six patients. Medicina (Kaunas) 56(12):642. https://doi.org/10.3390/medicina56120642
26. Tasiou A, Giannis T, Brotis AG, Siasios I, Georgiadis I, Gatos H, Tsianaka E, Vagkopoulos K, Paterakis K, Fountas KN (2017) Anterior cervical spine surgery-associated complications in a retrospective case-control study. J Spine Surg 3(3):444–459. https://doi.org/10.21037/jss.2017.08.03
27. Schleicher P, Kobbe P, Kandziora F, Scholz M, Badke A, Brakopp F, Ekkerlein H, Gercek E, Hartensuer R, Hartung P, Jarvers JS, Matschke S, Morrison R, Müller CW, Pishnamaz M, Reinhold M, Schmeiser G, Schnake KJ, Stein G, Ullrich B, Weiss T, Zimmermann V (2018) Treatment of injuries to the subaxial cervical spine: recommendations of the spine section of the German society for orthopaedics and trauma (DGOU). Global Spine J 8(2 Suppl):25S-33S. https://doi.org/10.1177/2192568217745062
28. Sharif S, Ali MYJ, Sih IMY, Parthiban J, Alves ÓL (2020) Subaxial cervical spine injuries: WFNS spine committee recommendations. Neurospine 17(4):737–758. https://doi.org/10.14245/ns.2040368.184

Authors and Affiliations

Vadim A. Byvaltsev[1,2,3] · Andrei A. Kalinin[1,2] · Evgenii G. Belykh[4] · Marat A. Aliyev[5,6] · Bair B. Sanzhin[1] · Alexander V. Kukharev[1] · Yermek K. Dyussembekov[5] · Valerii V. Shepelev[1,7] · K. Daniel Riew[8,9]

Andrei A. Kalinin
andrei_doc_v@mail.ru

Evgenii G. Belykh
belykhevgenii@gmail.com

Marat A. Aliyev
a.marat.a0903@mail.ru

Bair B. Sanzhin
bair-san@yandex.ru

Alexander V. Kukharev
kuharevav@mail.ru

Yermek K. Dyussembekov
ermek@mail.ru

Valerii V. Shepelev
shepelev.dok@mail.ru

K. Daniel Riew
kr2637@cumc.columbia.edu

1 Department of Neurosurgery, Irkutsk State Medical University, Irkutsk, Russia

2 Department of Neurosurgery, Railway Clinical Hospital, Irkutsk, Russia

3 Department of Traumatology, Orthopedic and Neurosurgery, Irkutsk State Medical Academy of Postgraduate Education, Irkutsk, Russia

4 Department of Neurosurgery, New Jersey Medical School, Rutgers University, New York, USA

5 Asfendiyarov Kazakh National Medical University, Almaty, Kazakhstan

6 Department of Neurosurgery, City Clinical Hospital No. 7, Almaty, Kazakhstan

7 Department of Neurosurgery, 1477 Clinical Hospital, Vladivostok, Russia

8 Department of Orthopedic Surgery, Columbia University, New York, NY, USA

9 Department of Neurological Surgery, Weill Cornell Medical School, New York, USA