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ORIGINAL ARTICLE

Predictors of failure after primary anterior cervical discectomy and fusion for subaxial traumatic spine injuries

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Abstract

Introduction Traumatic subaxial fractures account for more than half of all cervical spine injuries. The optimal surgical approach is a matter of debate and may include anterior, posterior or a combined anteroposterior (360º) approach. Analyzing a cohort of patients initially treated with anterior cervical discectomy and fusion (ACDF) for traumatic subaxial injuries, the study aimed to identify predictors for treatment failure and the subsequent need for supplementary posterior fusion (PF).

Methods A retrospective, single center, consecutive cohort study of all adult patients undergoing primary ACDF for traumatic subaxial cervical spine fractures between 2006 and 2018 was undertaken and 341 patients were included. Baseline clinical and radiological data for all included patients were analyzed and 11 cases of supplementary posterior fixation were identified.

Results Patients were operated at a median of 2.0 days from the trauma, undergoing 1-level (78%), 2-levels (16%) and $\geq$ 3-levels (6.2%) ACDF. A delayed supplementary PF was performed in 11 cases, due to ACDF failure. On univariable regression analysis, older age ($p = 0.017$), shorter stature ($p = 0.031$), posterior longitudinal ligament (PLL) injury ($p = 0.004$), injury to ligamentum flavum ($p = 0.005$), bilateral facet joint dislocation ($p < 0.001$) and traumatic cervical spondylolisthesis ($p = 0.003$) predicted ACDF failure. On the multivariable regression model, older age ($p = 0.015$), PLL injury ($p = 0.048$), and bilateral facet joint dislocation ($p = 0.010$) remained as independent predictors of ACDF failure.

Conclusions ACDF is safe and effective for the treatment of subaxial cervical spine fractures. High age, bilateral facet joint dislocation and traumatic PLL disruption are independent predictors of failure. We suggest increased vigilance regarding these cases.

Keywords Subaxial cervical spine fracture · Anterior cervical discectomy and fusion · Supplementary posterior

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Introduction

Traumatic subaxial cervical spine fractures constitute the majority of cervical spine injuries. Cases with low-grade instability may be treated nonsurgically with external cervical stabilization; while, cases with high-grade instability require fixation surgery. The surgical options include anterior, posterior, or combined anteroposterior (360°) fixations. However, the optimal surgical approach is still a matter of debate [1–4]. Anterior cervical instrumentation, including anterior cervical discectomy and fusion (ACDF) and corpectomy and fusion (ACCF) are common approaches for the treatment of subaxial cervical spine fractures. In a systematic review on 300 000 patients, early graft or instrumentation failure was reported in about 2% of all procedures [5]. The exact mechanisms behind construct failure are poorly described, but suboptimal implant placement [6] and poor bone quality [7] are important factors. Cases with unsatisfactory anterior fixations can be successfully managed with supplementary posterior fixations (PF) [6, 7]. However, in selected cases, repeat surgery can be avoided if anteroposterior (360) surgery is performed at index surgery. Recent studies show that patients with subaxial spine injuries were equally satisfied and reported similar health-related quality of life (HRQoL) measures, regardless of the surgical approach [8, 9]. Nonetheless, anteroposterior surgery is more extensive and carries greater surgical risks due to increased duration of surgery and two incision sites [8], necessitating well defined guidelines to support clinical decision making when identifying these cases [10]. The study sought to define predictors of ACDF failure and the need of PF in patients primarily treated with ACDF, aiming to identify patients that would benefit from an anteroposterior fixation at index surgery. Improved decision making at index surgery may reduce the likelihood for postoperative neurological deterioration, renewed surgery, longer hospital stay, and delayed rehabilitation.

Material and methods

Patient selection

This retrospective, single-center study was performed in accordance with the STROBE guidelines and was approved by the Regional Ethical Review Board (Dnr: 2016/1708–31/4) that waived the need for informed consent. The study hospital is a publicly funded tertiary care center serving a region of approximately two million inhabitants. It is the region's only level 1 trauma center and handles the majority of the spinal trauma cases in the region. Patients were identified through the surgical management software Orbit (Evry Healthcare Systems, Solna, Sweden). Medical records and imaging data from digital hospital charts were retrospectively reviewed using the health record software TakeCare (Compu Group Medical Sweden AB, Farsta, Sweden). A total of 415 adult patients treated with ACDF during the period of 2006 to 2018 were screened and 341 cases with traumatic injuries and complete records were included in the study. The inclusion criteria were traumatic subaxial cervical spine injury, treated with single- or multilevel ACDF at index surgery. The exclusion criteria were ankylosing spondylitis, non-traumatic cases, traumatic cases primarily treated with posterior or anteroposterior surgery, traumatic cases treated with ACCF and cases with incomplete records. Preoperative diagnostic imaging included, in the vast majority, an initial trauma CT scan followed by an MRI.

Surgical techniques

All surgeries were performed by one or more senior neurosurgeons. For ACDF, a standard right-sided Smith–Robinson approach was performed. Discectomy and osteophyte removal was performed with microsurgical technique to ensure spinal cord decompression, but the posterior longitudinal ligament was typically not opened unless disrupted due to the trauma. PEEK (polyetheretherketone) cages were used in all cases. Adequate alignment and correct position of the cage was confirmed by fluoroscopy. An anterior plate was then positioned, bridging the vertebrae above and below the cage(s) and stabilized with bicortical screws under fluoroscopic guidance.

Construct failure was defined as instrumentation failure, implant subsidence, loss of alignment, screw loosening or combinations of theses resulting in radiological instability.

Supplementary PF was performed with the patient in the prone position and the head fixed in a Mayfield clamp. A midline incision was used to expose the posterior aspects of the spine. Lateral mass screws were placed, typically 2 levels above and below the fracture. When needed, fixations were extended to the upper thoracic levels, where pedicle screws were placed. Cross-links were used when fixations extended 4 levels or more.

Postoperative follow-up

Patients were mobilized without collars after surgery. Postoperative neurological examination was performed within the first 24 h. Complications were categorized based on their severity grade according to the Ibanez classification scheme. [11] In adherence with routine protocols, all patients underwent a postoperative low-dose CT scan within 24 h from surgery and follow-up low-dose CT scans at approximately 4 weeks and 3 months after the initial surgery. All patients were clinically evaluated by their surgeon after 3 months. Additional imaging was performed if clinically indicated. When supplementary PF was performed, the above-mentioned follow-up imaging protocol was repeated.

Statistics

Categorical data are presented as numbers (proportions). The normality of continuous variables was evaluated using the Shapiro–Wilk test. Since all continuous variables deviated significantly from a normal distribution pattern, medians, and interquartile ranges (IQR) were used. To identify predictors of ACDF failure and the need for delayed PF, a univariable logistic regression was used with delayed PF as the outcome and possible predictors as explanatory variables. Factors that showed a trend toward significance in the univariate analysis ($p < 0.1$) were then entered into a step-down multivariable logistic regression to determine independent risk factors. In the stepwise model, the least significant variable was sequentially eliminated until only significant variables remained. Listwise deletion was used to handle missing data. Statistical significance was set to $p < 0.05$. All analyses were conducted using the statistical software program R (version 4.1.2).

Results

Baseline data

In total 415 patients with traumatic cervical spine injuries were screened and 74 were excluded due to ACCF ($n = 19$), prior cervical surgery ($n = 15$), ankylosing spondylitis ($n = 13$), or incomplete records ($n = 27$).

For the remaining 341 patients, the most common trauma mechanisms were motor vehicle accidents (32%), falls from a height (29%), and same level falls (27%). The most common injuries were anterior longitudinal ligament (ALL) disruptions (87%) followed by traumatic disc ruptures (63%). ALL disruptions in combination with other radiological signs of instability constituted unstable injuries. The preoperative ASIA-IS (AIS) grades were D (28%), C (16%), B (5.3%) and A (5.3%); while, 45% of the patients were neurologically intact (Table 1).

ACDF failure and delayed PF

Patients were operated at a median of 2.0 days from the trauma, undergoing 1-level (78%), 2-levels (16%) and ≥ 3-levels (6.2%) ACDF. Surgical site infections requiring antibiotic therapy occurred in 8 (2.3%) and requiring surgical revision in 3 (0.9%). One case of postoperative hematoma (0.3%) and one case of vertebral artery injury (0.3%) were reported (Table 2).

A delayed supplementary PF was performed in 11 cases (3.2%) within a median of 20 days from the index surgery (Table 3). In all cases PF was performed due to construct failure with radiological signs of instability. The patients in the PF group were older (medians 74 vs 59 years) and more frequently smokers (45% vs 32%). A posterior longitudinal ligament injury was seen in 9 (82%) and 7 (64%) had bilateral facet joint dislocation. A combined injury to the PLL, ligamentum flavum, and a bilateral facet dislocation was

Table 1 Baseline data

Variable	ACDF $n = 330$	ACDF + Delayed PF $n = 11$
Demographics		
Age (years), median (IQR)	59 (46–69)	74 (68–77)
Female sex	85 (26%)	5 (45%)
Height (cm), median (IQR)	178 (170–184)	166 (163–181)
BMI, median (IQR)	25 (23–28)	26 (23–28)
Smoker	105 (32%)	5 (45%)
AIS on admission	*2 missing*	
AIS A	15 (4.6%)	3 (27%)
AIS B	18 (5.5%)	0 (0%)
AIS C	53 (16%)	1 (9.1%)
AIS D	92 (28%)	3 (27%)
Neurologically intact	150 (46%)	4 (36%)
Trauma mechanism		
Motor vehicle accident	108 (32%)	3 (27%)
Fall from height	95 (29%)	5 (45%)
Same-level fall	88 (27%)	3 (27%)
Assault	9 (2.7%)	0 (0%)
Diving accident	4 (1.2%)	0 (0%)
Other	29 (8.8%)	0 (0%)
Radiographic data		
Preoperative CT	327 (99%)	11 (100%)
Preoperative MRI	323 (98%)	9 (82%)
ALL injury	285 (86%)	10 (91%)
PLL injury	104 (32%)	9 (82%)
Flavum injury	91 (28%)	8 (73%)
Traumatic disc rupture	208 (63%)	6 (55%)
Facet dislocation	85 (26%)	8 (73%)
Unilateral facet dislocation	43 (13%)	1 (9.1%)
Bilateral facet dislocation	42 (13%)	7 (64%)
Laminar fracture	75 (23%)	1 (9.1%)
Traumatic spondylolisthesis	100 (30%)	9 (82%)

Data are presented as median (IQR) or number (proportion). Abbreviations: *ALL* anterior longitudinal ligament, *AIS* American Spinal Cord Injury Association Impairment Scale, *BMI* body mass index, *cm* centimeters, *CT* computed tomography, *MRI* magnetic resonance imaging, *PLL* posterior longitudinal ligament, *IQR* Interquartile range

Table 2 Treatment and outcome data

Variable	ACDF $n = 330$	ACDF + Delayed PF $n = 11$
Days from trauma to index surgery, median (IQR)	2.0 (1.0–3.0)	1.0 (1.0–2.0)
ACDF range		
1 level	256 (78%)	10 (91%)
2 levels	54 (16%)	0 (0%)
3 levels	18 (5.5%)	1 (9.1%)
4 levels or more	2 (0.6%)	0 (0%)
Postoperative complication		
Local infection treated with antibiotics	7 (2.1%)	1 (9.1%)
Local infection treated with surgery	3 (0.9%)	0 (0%)
Local hematoma treated with surgery	1 (0.3%)	0 (0%)
CSF-leak treated with surgery	0 (0%)	0 (0%)
Vertebral artery injury	1 (0.3%)	0 (0%)
Days from ACDF to PF	–	20 (13–26)
Follow-up time (years)	4.7 (2.1–7.2)	5.0 (2.7–6.0)
AIS at follow-up	*6 missing*	
AIS A	7 (2.2%)	3 (27%)
AIS B	14 (4.3%)	1 (9.1%)
AIS C	22 (6.8%)	1 (9.1%)
AIS D	92 (28%)	2 (18%)
AIS E	44 (14%)	0 (0%)
Remained neurologically intact	145 (45%)	4 (36%)
Death at follow-up	88 (27%)	4 (36%)
Years to death, median (IQR)	5.1 (0.8–7.3)	4.6 (2.7–6.4)
Death due to cervical injury	11 (3.3%)	1 (9.1%)

Data are presented as median (IQR) or number (proportion). Abbreviations: *ACDF* anterior cervical discectomy and fusion, *AIS* American Spinal Cord Injury Association Impairment Scale, *CSF* cerebrospinal fluid, *PF* posterior fixation, *IQR* Interquartile range

seen in 27 patients, 6 of whom had failure (22%). A combined PLL, flavum injury, and either uni- or bilateral facet dislocation was seen in 49: of whom 7 had failure (14%). A combined PLL injury and bilateral facet dislocation was seen in 37: of whom 6 had failure (16%). In total, among these patients, 10 (91%) underwent 1-level and 1 (9%) a 3-level ACDF at index surgery (Tables 1 and 2). A median of 5-levels [range: 4–7] were treated with PF. One patient worsened neurologically after ACDF and before PF.

Predictors of ACDF failure and the need for delayed PF

In a univariable regression model designed to identify index surgery predictors of delayed PF, significant association was seen for age (OR = 1.06, $p = 0.017$), height (OR = 0.92, $p = 0.031$), PLL injury (OR = 9.78, $p = 0.004$), ligamentum flavum injury (OR = 7.00, $p = 0.005$), bilateral facet joint dislocation (OR = 12.0, $p < 0.001$), and traumatic spondylolisthesis (OR = 10.3, $p = 0.003$) (Table 4).

Of the above, step-down multivariable logistic regression identified age (OR = 1.07, $p = 0.015$), PLL injury (OR = 5.61, $p = 0.048$), and bilateral facet joint dislocation (OR = 6.54, $p = 0.010$) as independent predictors of ACDF failure and the need for delayed PF (Table 4).

On conditional density (CD) plot of the probability density of delayed PF (y-axis) as a function of age (x-axis), we observed an initial tentative increase in the probability density of delayed PF at 40 years, followed by a steep increase after 60 years (Fig. 1).

Discussion

In this single-center retrospective study of 341 consecutive cases of subaxial cervical spine fractures treated with ACDF and followed for 4.7 years, 3% exhibited ACDF failure that required supplementary PF within three weeks. Age over 60 years, PLL injury and bilateral facet joint dislocation were identified as independent predictors of ACDF failure and the need for supplementary PF. ACDF surgery is a common surgical approach for cervical injuries, but the choice of approach can vary depending on the nature of the injury as well as patient specific factors [7]. Predictors for

Table 3 Characteristics and outcomes of patients receiving delayed supplementary PF following ACDF failure

Age	Sex	Pre-op AIS	ALL injury	PLL injury	Flavum injury	Bilateral facet luxation	Traumatic spondylolisthesis	ACDF levels	Complication	PF levels	PF extent	Days from ACDF to PF	Indication for PF
74	Male	Intact	Yes	Yes	Yes	No	Yes	C6-C7	None	C5-Th2	5 levels	10	Construct failure
75	Female	Intact	Yes	No	No	Yes	Yes	C4-C7	None	C5-Th2	5 levels	34	Construct failure
77	Female	A	Yes	Yes	Yes	No	No	C5-C6	None	C4-Th1	5 levels	20	Construct failure
79	Male	C	Yes	Yes	Yes	Yes	No	C6-C7	None	C5-Th1	4 levels	7	Construct failure
82	Female	Intact	No	No	No	No	Yes	C2-C3	None	C1-C4	4 levels	20	Construct failure
55	Male	A	Yes	Yes	Yes	Yes	Yes	C7-Th1	Wound infection, antibiotics	C4-Th3	7 levels	24	Construct failure
69	Male	Intact	Yes	Yes	Yes	Yes	Yes	C6-C7	None	C5-Th1	4 levels	30	Construct failure
70	Female	D	Yes	Yes	Yes	Yes	Yes	C5-C6	None	C3-Th2	7 levels	27	Construct failure
66	Female	A	Yes	Yes	Yes	Yes	Yes	C5-C6	None	C4-Th1	5 levels	8	Construct failure
77	Male	D	Yes	Yes	No	No	Yes	C5-C6	None	C4-C7	4 levels	15	Construct failure
47	Male	D	Yes	Yes	Yes	Yes	Yes	C4-C5	None	C2-Th1	7 levels	25	Construct failure

Abbreviations: *ACDF* Anterior cervical discectomy and fusion, *AIS* American Spinal Injury Association Impairment Scale, *ALL* anterior longitudinal ligament, *PF* posterior fixation, *PLL* posterior longitudinal ligament. Construct failure was defined as: instrumentation failure, implant subsidence, loss of alignment, screw loosening or combinations of theses resulting in radiological instability

Table 4 Univariable and stepwise multivariable logistic regression predicting delayed posterior fixation following primary ACDF

Variable	Univariable model OR (95% CI)	*p*-value	Multivariable stepwise model OR (95% CI)	*p*-value
Age (years)	1.06 (1.01–1.11)	**0.017**	1.07 (1.02–1.13)	**0.015**
Female sex	2.40 (0.68–8.17)	0.157	–	–
Height (cm)	0.92 (0.86–0.99)	**0.031**	–	–
BMI	1.03 (0.89–1.17)	0.632	–	–
Smoking	1.79 (0.50–6.06)	0.347	–	–
AIS A or B on admission	3.35 (0.71–12.2)	0.085	–	–
PLL injury	9.78 (2.47–64.9)	**0.004**	5.61 (1.14–41.3)	**0.048**
Flavum injury	7.00 (1.98–32.5)	**0.005**	–	–
Traumatic disc herniation	0.70 (0.21–2.49)	0.569	–	–
Bilateral facet joint dislocation	12.0 (3.47–47.5)	**< 0.001**	6.54 (1.64–30.2)	**0.010**
Traumatic spondylolisthesis	10.3 (2.61–68.7)	**0.003**	–	–
≥ 3 level anterior fixation	1.55 (0.08–8.72)	0.683	–	–

Pseudo-R^2 for the multivariable model = 0.31. Abbreviations: *ACDF* anterior cervical discectomy and fusion, *AIS* American Spinal Cord Injury Association Impairment Scale, *CI* confidence interval, *OR* odds ratio. Bold text in the *p*-value column indicates statistical significance

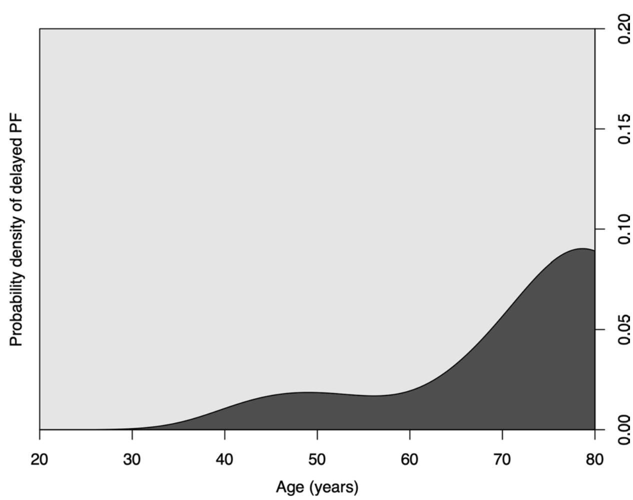

Fig. 1 Conditional density (CD) plot of the probability density of delayed PF (y-axis) as a function of age (x-axis)

reoperation, or complications that may lead to reoperation are poorly studied in traumatic ACDF compared to ACDF for degenerative disorders [12–15]. An anterior approach is suitable for most subaxial cervical injuries where the main goals are spinal cord decompression, restoration of alignment, and fusion of the injured segments [7, 16]. Factors such as a fracture's involvement of the vertebral body or the presence of a traumatic disc rupture are considered before the decision of surgical approach [7]. Other criteria that determine the management strategy are individual patient aspects such as age, general health, comorbidities, and bone quality. Brodke et al. compared the outcomes of 52 patients with reduced unstable cervical fractures and spinal cord injuries, randomized to either anterior or posterior stabilization. They reported that there were no significant differences in fusion rates, neurological recovery or long-term complaints of pain with regards to the chosen approach [17]. In general, the anterior approach offers easier access to the vertebra and the disc while also utilizing a safer supine patient position [18]. The anterior approach has, however, some limitations. Johnson et al. reported a 13% failure rate for traumatic superior endplate compression fractures, which required a supplementary PF [19].

Historically, several models to assess cervical spine stability have been proposed. Holdsworth described a two-column model where the posterior column including the posterior bony structures and the posterior ligaments was the key to maintaining stability [20]. In the three-column concept of spinal stability proposed by Denis, the middle column consisting of the posterior longitudinal ligament (PLL), the posterior one-third of the vertebral body and the intervertebral disc was the key to stability [21]. A stage 2 distractive-extension injury according to the Spine Trauma Study Group classification, is considered extremely unstable due to injury to the PLL with retrolisthesis of the cephalad vertebra which may result in spinal cord compression [22]. Our findings are well in line with these classification models where a PLL injury is an independent predictor of greater instability. Similarly, bilateral facet joint injury, a posterior column injury is indicative of greater instability and was also identified as an independent predictor of ACDF failure.

Cadaveric, biomechanical studies on bilateral facet joint injuries have reported superior stabilization when PF was performed compared to ACDF [23, 24]. Failure rates of 5–54%, after ACDF for facet joint injuries have been reported [19, 25, 26]. This variability could be due to differences in the relative contribution of uni- and bilateral facet joint injuries, small sample sizes and differences in surgical techniques and instrumentations. However, several clinical studies report successful treatment results with ACDF, with high fusion and low infection rates [19, 25, 27, 28]. Suggested solutions to lower failure rates include plates with screw locking mechanism, use of longer (bicortical) screws, accentuating the lordosis and avoiding large interbody grafts to prevent facet distraction [29]. Anissipour et al. described a series with 16 unilateral and 20 bilateral facet dislocations treated with ACDF [29]. The failure rate was 8% and the main predictor was endplate fracture at the inferior level. Johnson et al. described 65 bilateral and 22 unilateral single segment facet injuries in a cohort with the mean age of 37 years [19]. In their study, the authors could not identify a correlation between facet injury and failure; while, they found that injuries at C6-C7 were at higher risk of failure. The strongest correlation with radiographic failure was with endplate fractures. We had a similar failure rate due to facet joint dislocation and found it to be an independent predictor of failure. Other dissimilarities include the considerably higher age in our cohort (60 vs 37 years). Age at surgery was identified as an independent and significant predictor of ACDF failure and subsequent PF, in our study. The need for supplementary PF in our material rises steeply after the age of 60 years (Fig. 1). Age has previously been identified as a risk factor for medical complications. However, reports on surgical complications after ACDF due to age are scarce [30–33].

Our findings indicate that ACDF is a safe and effective method for surgical stabilization in subaxial cervical spine injuries with 97% success rate and mostly minor complications. A subgroup of 11 patients (3%) exhibited ACDF failure and required a supplementary PF in the early postoperative period (Table 3). These cases were mainly older patients with factors contributing to a higher degree of instability (i.e., three-column injury). We argue that a staged PF in immediate proximity to the index surgery could have been considered in these cases.

Strengths and limitations

The strengths of this study reside in its large sample size, availability of radiological imaging at injury and follow-up, and the long follow-up period. The limitations are inherent to the retrospective and single-center design of the study. Also, no patient-reported outcome measures reflecting the health-related quality of life in this patient group were available.

Conclusion

Conclusions: ACDF is a safe and effective approach for the treatment of subaxial cervical spine fractures, with a relatively low failure rate of 3%. Our findings indicate that high age, bilateral facet joint dislocation, and traumatic PLL disruption are independent predictors of failure. Increased vigilance is hence warranted in these cases and alternative approaches including a combined anteroposterior one may be considered at index surgery. This study provides pivotal insights for the informed decision-making when treating patients with traumatic subaxial spine injuries.

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Declarations

Conflict of interest None of the authors report any conflict of interest.

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