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Outcome and complications of operatively treated subaxial cervical spine injuries: A population-based retrospective cohort study

Joel Alve[a,b], Jukka Huttunen[b], Ville Leinonen[a,b], Henna-Kaisa Jyrkkänen[b,1], Nils Danner[b,1,*]

[a] *Department of Medicine, University of Eastern Finland, Kuopio, Finland*
[b] *Department of Neurosurgery, Neurocenter, Kuopio University Hospital, Kuopio, Finland*

A R T I C L E I N F O

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A B S T R A C T

Objective: The aim was to study the outcome and complications of operative treatment for subaxial cervical spine injuries with respect to injury morphology and surgical strategy.
Methods: A population-based cohort of 271 consecutive patients treated at Kuopio University Hospital from 2003 to 2018 was retrospectively reviewed.
Results: The mean age was 52.4 (range 12–90) years and 78.6% were male. The AOSpine morphological classification was C in 56.5%, B in 24.7% and A in 17.0% of cases. The surgical approach was anterior in 70.8%, posterior in 20.3% and combined in 8.9% of patients. Fixation alignment was maintained in 96.9% of patients. Instrumentation failures were observed only in patients operated anteriorly but no statistical difference was found between the surgical approaches. The American Spinal Injury Association Impairment Scale (AIS) grade improved in 22.1% of patients. Patients with preoperative AIS grade C had significant potential for neurological improvement (OR 10.44; 95% CI 1.77–61.56; $p = 0.010$). Postoperative, mostly mild, complications manifested in 22.5% of patients. The posterior approach was associated with fewer postoperative complications (OR 0.18; 95% CI 0.06–0.51; $p = 0.001$). Preoperative AIS grade A was a significant predisposing factor for complications (OR = 4.90; 95% CI = 1.49–16.10; $p = 0.009$). The perioperative (90-day) mortality rate was 3.3%. The mean follow-up period was 64.7 ± 25.9 (radiological)/136.7 ± 174.8 (clinical) days.
Conclusions: Operative treatment is safe and effective but the surgical approach should be patient- and injury-specific. The prognosis for neurological recovery from spinal cord injury is superior in patients with partially preserved motor function.

1. Introduction

Cervical spine injuries (CSI) are diagnosed in 3.5–3.7% of all trauma patients.[1,2] In the Nordic countries the annual incidence of CSIs has been reported to vary between 9.2 and 15.0/100,000.[3,4] In Finland, the average incidence of fatal CSIs between 1987 and 2010 was 16.5/1,000,000/year.[5] The leading causes of CSIs are road traffic collisions and falls.[1] The male gender is over-represented, and alcohol is involved in a quarter of all blunt trauma patients with a CSI.[6–8]

Subaxial cervical spine injuries (SCSIs) comprise the majority of all CSIs with the most commonly affected segments being between C5 and C7.[6,9] CSIs carry a risk of spinal cord injury (SCI), with fractures involving facet dislocation imposing the most severe neurological damage.[10,11] SCIs can result in devastating effects on an individual level, but they also pose an economical burden on the society.[12–14] Surgical stabilization of SCSIs is superior to conservative treatment especially in higher grade injuries.[15] The aim of surgery is to stabilize the spine, render it painless and minimize secondary neural tissue damage, while retaining the spinal alignment and maximum possible movement.[16] Surgical stabilization of the cervical spine can be performed via anterior, posterior or combined approach. Regarding the non-degenerative spine, there is no consensus on the best approach, and thus treatment should always be individualized according to the type of bony, ligamentous and neural injury.[15] SCSIs may be treated via anterior, posterior or 360-degree combined approach. Traditionally posterior or combined surgery has been recommended for patients with translation fractures (AO C).[15–17] In recent literature this has been challenged and suggested that even translation fractures could be treated by a mere anterior

* Corresponding author. Neurocenter – Neurosurgery, Kuopio University Hospital, Puijonlaaksontie 2, P.O.B. 100, 70029 KYS, Kuopio, Finland.
E-mail address: nils.danner@kuh.fi (N. Danner).

[1] Shared last authorship.

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approach.[18–21] However, in an unselected population patient-specific factors and comorbidities influence the treatment decisions and outcomes. The rationale of the current study was to compare the different operative strategies with their complication and outcome profiles in a population-based setup.

2. Material and methods

2.1. Study environment and population

Kuopio University Hospital (KUH) is a tertiary center responsible for the operative treatment of all CSIs in its catchment area. The population in the KUH catchment area was 824,956 at the start of the evaluation period (31 December 2002) and 805,133 at the end of it (31 December 2018).[22] The patients were identified from a register including all patients who underwent surgery due to cervical spine injury from January 1st 2003 to December 31st 2018. The Nordic Classification of Surgical Procedures (NCSP) and the Finnish version of the International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10), were used to identify the patients for the study. The following codes were used: NAJxx and NAGxx from NCSP and S12. x, S13. x and S14. x from ICD-10. All patients operated at KUH Department of Neurosurgery due to SCSIs during the study period were retrospectively reviewed. Exclusion criteria were surgery of the upper cervical spine (C0–C2), no CT or MRI available on admission, missing follow-up data, non-traumatic (tumor or degenerative process) surgery indication. The ICD-10 code search also identified patients with surgical treatment for other injuries, while the CSI was treated conservatively. These patients were also excluded.

2.2. Clinical data

The medical records of all patients were reviewed. Epidemiological data was gathered and American Spinal Injury Association Impairment Scale (AIS) grades were attributed.[23] If physical examination did not present evidence of neurological impairment preoperatively and there was no pre-existing spinal cord injury, classification "no spinal cord injury" was given. The AIS grade was determined according to the latest preoperative examination and at the last clinical control. The surgical method and type of instrumentation were determined from operation reports and radiographs. The surgical strategies were classified by the approach as anterior, posterior or combined (360-degree). The length of the posterior instrumentation was reported according to the number of intervertebral levels fused.

2.3. Injury classification

The injury morphology was classified from CT and/or MRI images using the AOSpine SCSI classification system (Fig. 1).[24] All imaging studies were systematically reviewed and cross-checked by two authors. Ambiguous cases were further discussed to find a consensus on the classification of the injury. Ankylosing spondylitis (AS) and diffuse idiopathic skeletal hyperostosis (DISH) were diagnosed radiologically. In the presence of major injuries (AOSpine A3-4, B1-3 and C), only the main injury guiding the surgical decision making was recorded. Major injuries presenting at multiple levels were separately specified. Minor injuries presenting on a level other than the major one were not recorded. Due to the size of the study population, these deviations from the AOSpine system were made in order to render the data interpretable.

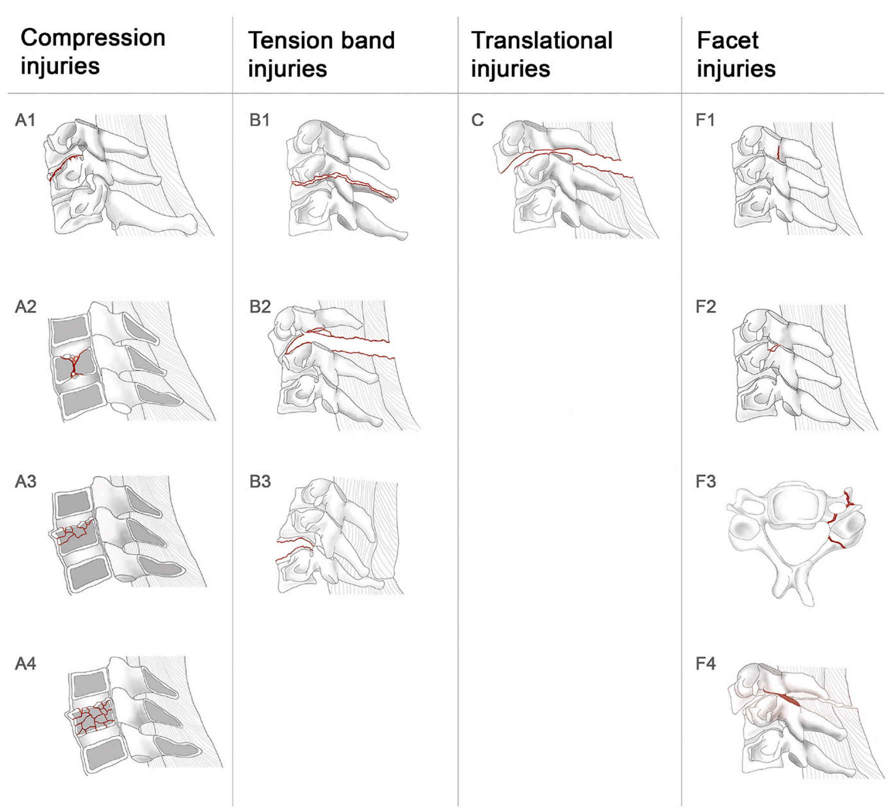

Fig. 1. AOSpine subaxial cervical spine injury classification system.
Modified from Vaccaro et al.[24] A1, wedge compression; A2, split; A3, incomplete burst; A4, complete burst; B1, posterior bony tension band injury; B2, posterior tension band injury; B3, anterior tension band injury; C, translational injury; F1, non-displaced facet injury; F2, facet injury with potential for instability; F3, floating lateral mass; F4, facet (sub)luxation.

2.4. Follow-up protocol and outcome measures

The primary outcome measure was fixation failure, and the secondary outcome measure was postoperative complications. The following specific complications were screened for: pneumonia, hoarseness, swallowing difficulties, swelling restricting airways, perforation of the esophagus, wound infection, postoperative hematoma leading to surgical evacuation, pulmonary embolism, sepsis and implant malposition leading to revision surgery. The standard clinical and radiological follow-up period for SCSI patients operated at KUH neurosurgery was 2–3 months in case of uneventful recovery. For complications and instrumentation failure, data was gathered until the end of the study period. Intraoperative implant malposition leading to later revision surgery was recorded as a complication, not a failure of instrumentation.

2.5. Statistical methods

Statistical analyses were performed using IBM SPSS Statistics 27 (IBM Corp. Armonk, NY, USA). Fisher's exact test was performed to identify statistically significant differences between categorical variables in 2 by 2 tables, while for tables larger than 2 by 2, the Fisher-Freeman-Halton modification was used. Mann–Whitney *U* test was used with the combination of categorical and numeric variables. Binary logistic regression was performed to find significant predictors of outcome and complications. Investigated covariates for the dependent variable "maintained alignment at follow-up" were patient age, gender, AOSpine classification (A, B, C or F only), facet status (no, unilateral or bilateral injury), number of cervical levels with a major injury, surgical approach (anterior, posterior or combined) and AIS grade preoperatively (A, B, C, D, E or no injury). Investigated covariates for the dependent variables "improvement of AIS grade at follow-up" and "deterioration of AIS grade at follow-up" were patient age, gender, AOSpine classification, surgical approach, AIS grade preoperatively and maintained fixation alignment at follow-up (implying a reoperation if the fixation had failed). Investigated covariates for the dependent "presence of postoperative complications" were patient age, gender, AOSpine classification, surgical approach, AIS grade preoperatively, and maintained fixation alignment. AIS grade deterioration was also considered as a complication in this analysis.

2.6. Ethical approval

This study was carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) and approved by the Ethics Committee of KUH District, Kuopio, Finland (permission number 236/2017). Due to the retrospective nature of the study no informed consent was required.

3. Results

3.1. Descriptive data of the study cohort

During the study period, 271 patients meeting the inclusion criteria were operated (Fig. 2) .

Demographic data and injury characteristics of the study population are shown in Table 1. The most injured segments were intervertebral levels between C6–C7 (30.3%) and C5–C6 (26.9%) (Table 2).

In the last preoperative examination, no evidence of SCI was found in 116 (42.8%) cases. AIS grade A was attributed to 18 (6.6%), B to 11 (4.1%), C to 22 (8.1%) and D to 90 (33.2%) patients. If a patient had a pre-existing SCI affecting motor and/or sensory function and the status remained unchanged after the current injury, AIS was graded as E (3 patients, 1.1%). In 11 (4.1%) cases, preoperative AIS grade could not be determined from the medical records.

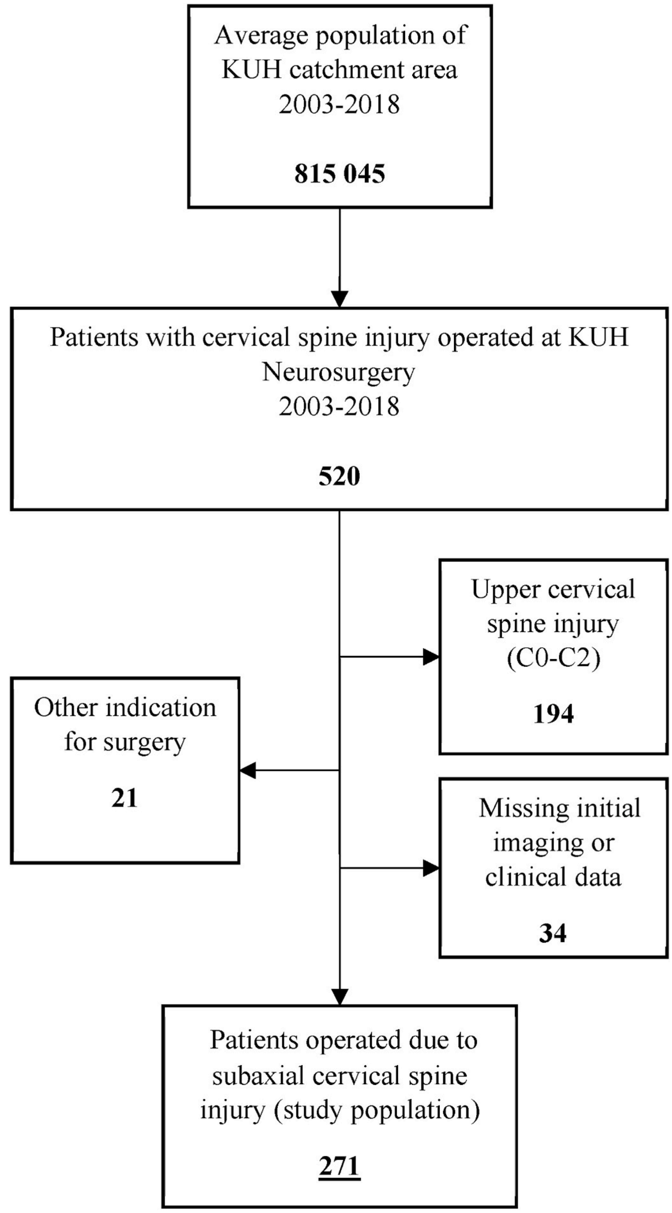

Fig. 2. Flow chart of the study population. KUH, Kuopio University Hospital.

3.2. Operative treatment and follow-up

The applied approaches and instrumentations are given in Table 3. Short-segment fixation (one or two intervertebral levels) was applied in 12.7% of patients who underwent surgery via the posterior approach and in 12.5% of patients who underwent surgery via the combined approach. In patients treated with screw fixation, lateral mass screws were used in the subaxial cervical spine. The mean time from primary surgery to first radiological follow-up after discharge was 64.7 ± 25.9 (range 7–168) days and the mean time from primary surgery to last clinical follow-up visit was 136.7 ± 174.8 (range 18–1627) days. Postoperative complications related to each surgical approach are presented in Table 4. In total, 61 (22.5%) patients presented with postoperative complications. There was no statistical significance in complication rates between different surgical approaches.

Nine (3.3%) patients died before their first radiological or clinical follow-up visit (Fig. 3). There were no fixation failures in deceased patients (Table 5). Mean time from primary surgery to death was 10 ± 8.9 (range 2–26) days. The deceased patients were significantly older

Table 1
Characteristics of subaxial cervical spine injury patients operated at Kuopio University hospital department of neurosurgery 2003–2018 included in the study ($n = 271$).

Gender, male/female	
n	213/58
%	78.6/21.4
Age, years	
mean ± SD	52.4 ± 22.0
Range (min–max), years	12–90
Mechanism of injury, n (%)	
Ground level fall	88 (32.8)
Motor vehicle accident	71 (26.2)
Fall from height or stairs	53 (19.6)
Diving into shallow water	18 (6.6)
Non-motor vehicle accident	9 (3.3)
Sports injury	7 (2.6)
Trampoline accident	7 (2.6)
Assault	6 (2.2)
Falling object	3 (1.1)
Traffic accident as a pedestrian	2 (0.7)
Miscellaneous/Unclear	6 (2.2)
Under the influence of alcohol, n (%)	77 (28.4)
AS, n (%)	46 (17.0)
DISH, n (%)	10 (3.7)
AOSpine morphological type, n (%)	
A	46 (17.0)
A0	*1 (0.4)*
A1	*5 (1.8)*
A2	*0 (0.0)*
A3	*8 (3.0)*
A4	*32 (11.8)*
B	67 (24.7)
B1	*6 (2.2)*
B2	*22 (8.1)*
B3	*39 (14.4)*
C	153 (56.5)
F only	5 (1.8)
Facet injury, n (%)	
No	52 (19.2)
Unilateral	87 (32.1)
Bilateral	132 (48.7)
F3	16 (5.9)
F4	172 (63.5)
Injury level, n (%)	
Single-level injury	255 (94.1)
Two-level injury	15 (5.5)
Three-level injury	1 (0.4)

SD, standard deviation; AS, ankylosing spondylitis; DISH, diffuse idiopathic skeletal hyperostosis.

Table 2
Subaxial cervical spine injury levels in the study cohort ($n = 271$).

Injury level	n (%)
Single-level injury	255 (94.1)
C3–C4	*13 (4.8)*
C4–C5	*33 (12.2)*
C5–C6	*73 (26.9)*
C6–C7	*82 (30.3)*
C7–Th1	*8 (3.0)*
C4	*6 (2.2)*
C5	*6 (2.2)*
C6	*12 (4.4)*
C7	*22 (8.1)*
Two-level injury	15 (5.5)
C5 and C6	*5 (1.8)*
C6 and C7	*4 (1.5)*
C5–C6 and C6–C7	*3 (1.1)*
C6–C7 and C7–Th1	*1 (0.4)*
C4–C5 and C5–C6	*2 (0.7)*
Three-level injury	1 (0.4)
C4 and C5 and C6	*1 (0.4)*

Cx-Cy, injury located at the intervertebral level between vertebra x and y.

Table 3
Surgical approaches and instrumentations used in the study cohort ($n = 271$).

Anterior approach, n (% of study cohort)	**192 (70.8)**
Cage and plate, n (% of anterior approach)	144 (75)
VBS, n (% of anterior approach)	29 (15.1)
Plate, n (% of anterior approach)	13 (6.8)
Plate and BG, n (% of anterior approach)	4 (2.1)
Cage, plate and BG, n (% of anterior approach)	1 (0.5)
Cage, n (% of anterior approach)	1 (0.5)
Posterior approach, n (% of study cohort)	**55 (20.3)**
Length of posterior fusion, intervertebral levels, mean ± SD	*4.0 ± 1.5*
Range (min–max), intervertebral levels	*1–7*
Screws, n (% of posterior approach)	30 (54.5)
Hooks and screws, n (% of posterior approach)	13 (23.6)
Hooks, n (% of posterior approach)	9 (16.4)
Laminectomy only, n (% of posterior approach)	3 (5.5)
Combined approach, n (% of study cohort)	**24 (8.9)**
Length of posterior fusion, intervertebral levels, mean ± SD	*3.6 ± 1.2*
Range (min–max), intervertebral levels	*1–6*
Cage, plate and hooks, n (% of combined approach)	6 (25)
VBS and screws, n (% of combined approach)	5 (20.8)
Cage, plate and screws, n (% of combined approach)	4 (16.7)
Plate, BG, hooks and screws, n (% of combined approach)	3 (12.5)
Plate, hooks and screws, n (% of combined approach)	2 (8.3)
Cage and screws, n (% of combined approach)	1 (4.2)
Cage, plate, hooks and screws, n (% of combined approach)	1 (4.2)
VBS and hooks, n (% of combined approach)	1 (4.2)
VBS, hooks and screws, n (% of combined approach)	1 (4.2)

VBS, vertebral body substitute; BG, bone graft; SD, standard deviation.

compared to the rest of the population, 69.9 ± 23.2 (range 27–90) years vs. 51.8 ± 21.2 (range 12–90) years ($p = 0.007$).

Outcomes and total postoperative complication rates according to surgical approach and injury morphology are presented in Table 6. Maintained fixation alignment was achieved in 254 (96.9%) cases during the entire study period. Postoperative failure of instrumentation leading to reoperation occurred in 8 (3.1%) patients (Table 7) and the mean time from primary surgery to reoperation was 82.4 ± 84.7 (range 14–268) days. All patients with fixation failure were operated via anterior approach ($p = 0.325$). AIS improved from the primary situation to follow-up in 58 (22.1%) patients. AIS deteriorated in 3 (1.1%) patients, all of whom had an AOSpine C injury ($p = 0.737$). One of these patients was operated anteriorly and 2 posteriorly ($p = 0.222$).

3.3. *Predictors of outcome and complications*

In the regression analyses no significant predictors for maintained alignment or fixation failure at follow-up were found. The only statistically significant predictor of improvement of AIS grade at follow-up was AIS grade C preoperatively (OR 10.44; 95% CI 1.77–61.56; $p = 0.010$). No predictors for AIS grade deterioration were found. Preoperative AIS grade A was a predictor of postoperative complications (OR 3.92; 95% CI 1.20–12.77; $p = 0.024$), whereas a posterior operative approach was associated with fewer postoperative complications (OR 0.28; 95% CI 0.10–0.83; $p = 0.021$).

4. Discussion

This population-based cohort study with 271 patients showed that surgical treatment of SCSIs provides excellent outcomes. Fixation alignment can be maintained in all AO groups regardless of injury morphology. There was no intraoperative mortality. Nine patients

Table 4
Postoperative complications according to surgical approach in the study cohort ($n = 271$).

	Anterior approach $n = 192$	Posterior approach $n = 55$	Combined approach $n = 24$	Total $n = 271$	p[a]
Patients with any complication	48 (25.0)	6 (10.9)	7 (29.2)	61 (22.5)	0.051
Pneumonia	18 (9.4)	3 (5.5)	3 (12.5)	24 (8.9)	0.536
Hoarseness	15 (7.8)	–	1 (4.2)	16 (5.9)	0.053
Swallowing difficulties	12 (6.3)	1 (1.8)	1 (4.2)	14 (5.2)	0.447
Wound infection	3 (1.6)	1 (1.8)	2 (8.3)	6 (2.2)	0.144
Swelling restricting airways	2 (1.0)	–	1 (4.2)	3 (1.1)	0.356
Postoperative hematoma leading to surgical evacuation	3 (1.6)	–	–	3 (1.1)	1.000
Pulmonary embolism	1 (0.5)	1 (1.8)	–	2 (0.7)	0.511
Sepsis	1 (0.5)	1 (1.8)	–	2 (0.7)	0.511
Perforation of the esophagus	2 (1.0)	–	–	2 (0.7)	1.000
Implant malposition leading to revision surgery[b]	1 (0.5)	–	1 (4.2)	2 (0.7)	0.233
Missing data	15 (7.8)	3 (5.5)	0 (0.0)	18 (6.6)	

Patient numbers are reported as n (%).
[a] Fisher-Freeman-Halton exact test.
[b] Intraoperative implant malposition leading later to revision surgery was recorded as a complication, not a failure of instrumentation.

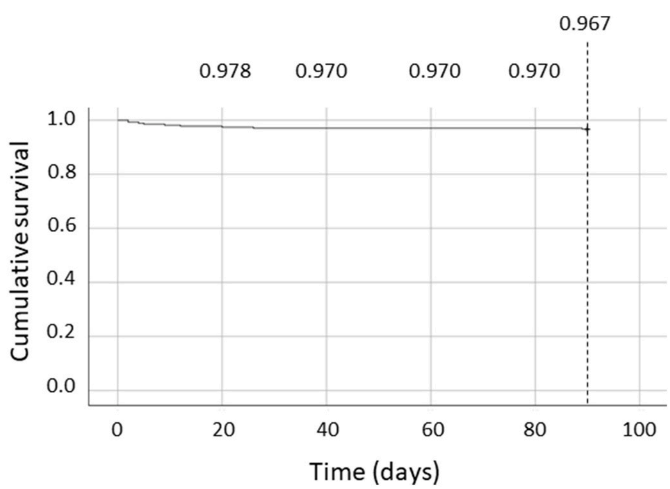

Fig. 3. Kaplan–Meier analysis of 90-day mortality after surgery. Cumulative survival is presented at each time-point.

(3.3%) died during the perioperative period (within 90 days after surgery). One of these patients suffered a postoperative wound infection leading to sepsis. In the remaining patients pre-existing medical conditions, injury severity and high age were contributing factors. No deaths were associated with instrumentation failure. Only eight patients (3.0%) experienced fixation failure, one of which was due to a fall during the postoperative recovery period. Maintained alignment was achieved in 95.7% of the anteriorly operated group vs. 100% in the posterior and combined groups with no statistical difference between the groups. Also other studies with large patient-populations have concluded that an additional posterior stabilization is required in patients with significant trauma of the posterior elements or irreducible bilateral facet dislocation.[25,26] In the general population, the prevalence of osteoporosis grows with age and in cervical spine surgery, it has been associated with an increased risk of revision surgery.[27,28] In the study population, four of the eight patients with instrumentation failure were over 75 years old. Accordingly, a perioperative predisposing event for poor outcome could mostly be pinpointed from the medical records of the patients (Tables 5 and 7). In patients with a rigid spine due to e.g. AS, DISH or severe degeneration, the injury morphology may not reveal its true nature in a CT scan. In these patients, a seemingly benign-looking fracture may be an indicator of a highly unstable injury. Accordingly, a posterior or combined surgical approach is recommended to achieve sufficient stability and a favorable outcome.[15] In the regression analyses of the current study, AS and DISH were not used as covariates, since these patients were mainly operated via posterior or combined approach also in our practice. However, of the anteriorly operated 8 patients with postoperative fixation failure, two had AS and one had DISH. In one case, a combined surgical approach was attempted, but the patient did not tolerate the prone position needed for posterior fixation. In the two remaining cases, no apparent reason for opting to use solely the anterior approach could be determined. Two of the younger patients with type C fractures were re-operated several months after initial surgery, likely reflecting postoperative kyphosis rather than actual instrumentation failure. This emphasizes the need for radiographical follow-up in case an anterior approach is chosen in translation injuries. A preoperative AIS grade C was associated with better potential for postoperative neurological recovery. This finding is in line with a recent meta-analysis summarizing that neurological recovery significantly differs between all grades of SCI severity in the following order: $C > B > D > A$.[29] Thus, the most active treatment and rehabilitation should be targeted especially to patients with a partial spinal cord injury. Timing of surgery within a shorter interval from the injury to the spinal cord decompression has been associated with improved outcome and an expert consensus has recently been reached advocating for early decompression of high grade injuries.[17,30] In the setup of the current study, no timeline analysis from injury to surgery could be performed. Considering that nerve function is expected to improve for more than a year after a SCI, our study is limited regarding the analysis of AIS evolution due to the short clinical follow-up period available.

Only 3 patients presented with AIS grade deterioration at follow-up. In one patient this was attributed to postoperative fixation failure two weeks after surgery, resulting in AIS grade D converting to C. In the two other patients, no obvious reason for worsening of the neurological status could be identified. Both were operated via posterior approach with no spinal cord injury preoperatively nor immediately postoperatively but presented with AIS grade D at follow-up. These patients exhibited highly unstable AOSpine C injuries, especially vulnerable to any mobilization related complications. Intraoperative neuromonitoring could provide an additional safety element for these patients but the availability is limited in an acute setting. Another possible explanation is that the mild nature of these patients' neurological impairment might have led to the SCI being missed at the initial stage. Furthermore, there were no postoperative MRI available to allow reliable differentiation between SCI and nerve root compression. Complication rates were 10.9%, 25.0% and 29.2% for posterior, anterior and combined approaches respectively (Table 4). Pneumonia was the most common postoperative complication, followed by hoarseness which, as expected, was only present in patients that underwent anterior or combined surgery. Swallowing difficulties manifested in 12 (6.3%) anteriorly operated patient and 1 (4.2%) patient operated via combined approach. Interestingly, one (1.8%) posteriorly operated patient also presented with swallowing difficulties, which may be attributed to intubation or trauma-related swelling.

Table 5
Perioperative (90-day) mortality ($n = 9$).

Age (years), Gender	AS or DISH	Preoperative AIS grade	AOSpine classification	Surgical approach	Postoperative complications	Factors contributing to death	Days from primary operation to death
27, M	–	A	C6: A3 (F2 BL) and C7: A4	anterior	–	spinal shock, respiratory and cardiac failure	12
35, M	–	B	C4–C5: C (F4)	anterior	pneumonia	traumatic brain injury, pneumothorax and respiratory failure	89
65, M	–	C	C6–C7: C (F4 BL)	anterior	–	postoperative delirium, cause of death unclear	5
79, M	AS	C	C5–C6: C (F4)	anterior	pneumonia	respiratory and cardiac failure	20
81, M	AS	D	C6–C7: B1 (F2)	posterior	wound infection, sepsis	sepsis, respiratory and cardiac failure	26
82, M	AS	C	C5–C6: B3 (F4)	posterior	pneumonia	respiratory failure	9
84, F	AS	D	C4–C5: C (F4 BL)	anterior	pneumonia	respiratory failure	2
86, M	–	D	C4–C5: C (F4)	anterior	pneumonia	hip fracture and pre-existing heart failure	4
90, M	–	A	C5–C6: C (F4 BL)	anterior	–	pre-existing heart failure	2

M, male; F, female; AS, ankylosing spondylitis; DISH, diffuse idiopathic skeletal hyperostosis; AIS, American Spinal Injury Association Impairment Scale.

Table 6
Outcomes and total postoperative complication rates according to surgical approach and injury morphology at follow-up ($n = 262$).

	AOSpine A	AOSpine B	AOSpine C	AOSpine F	Total
Anterior approach	36	36	108	5	185
Alignment maintained	35 (97.2)	35 (97.2)	102 (94.4)	5 (100)	177 (95.7)
AIS improvement	6 (16.7)	7 (19.4)	27 (25.0)	3 (60)	43 (23.2)
AIS deterioration	0 (0.0)	0 (0.0)	1 (0.9)	0 (0.0)	1 (0.5)
Postoperative complications	8 (22.2)	11 (30.6)	25 (23.1)	0 (0)	44 (23.8)
Posterior approach	5	21	27	–	53
Alignment maintained	5 (100)	21 (100)	27 (100)	–	53 (100)
AIS improvement	1 (20)	6 (28.6)	5 (18.5)	–	12 (22.6)
AIS deterioration	0 (0.0)	0 (0.0)	2 (7.4)	–	2 (3.8)
Postoperative complications	0 (0.0)	2 (9.5)	2 (7.4)	–	4 (7.5)
Combined approach	4	8	12	–	24
Alignment maintained	4 (100)	8 (100)	12 (100)	–	24 (100)
AIS improvement	1 (25)	1 (12.5)	1 (8.3)	–	3 (12.5)
AIS deterioration	0 (0.0)	0 (0.0)	0 (0.0)	–	0 (0.0)
Postoperative complications	1 (25.0)	2 (25.0)	4 (33.3)	–	7 (29.2)

Patient numbers are reported as n (%). Only patients alive at follow-up are included. AIS, American Spinal Injury Association Impairment Scale.

Wound infection was rather rare, occurring in 6.3% of anteriorly operated, 1.8% of posteriorly operated and in 8.3% of patients with a combined approach. Perforation of the esophagus complicated 2 (1.0%) anterior operations, one of which led to sepsis. In the posterior group, the only wound infection also led to sepsis (1.8%). Patients with AIS grade A preoperatively had a significantly increased risk for complications compared to patients with no SCI. Jaja et al. have previously linked AIS grade A with a significantly higher rate of pneumonia, wound infections and sepsis compared to less severe SCIs.[31] In our study, the posterior surgical approach was associated with a decreased risk for postoperative complications. Leckie et al. found in their database with over 1000 patients that complications occurred more frequently in posterior and combined procedures than in anterior procedures.[32] The higher complication rate in anterior surgeries in our results is explained by the recording of hoarseness and swallowing difficulties as complications. These are characteristic for the anterior approach but usually mild and transient. In our retrospective setting, it was not possible to categorically assess if actual damage to the recurrent laryngeal nerve had been done during surgery (permanent) or if these symptoms were caused by normal postoperative swelling (transient). Operative treatment of SCSIs is safe and effective. The outcomes and complications in our study (Tables 4–7) were in line with literature reporting a similar population-based cohort,[33] whereas in selected patient groups and register studies surprisingly low complication rates are reported, likely due to some degree of selection and reporting bias.[26,34] Since it is demanding and time-consuming to conduct large-scale prospective or randomized studies in this field, we believe that population-based cohorts provide invaluable support for decision making in clinical practice. SCSIs with AIS grade C had a notable potential for rapid neurological improvement after surgery.

4.1. Limitations

The retrospective design of this study sets some limitations to the interpretation of the results. The patient number of the study is relatively high but it does not allow a direct comparison between the surgical strategies in a specific injury type, since the most suitable treatment option was individually selected based on patient- and injury-specific factors. Furthermore, the categorization of surgical strategies by the approach is a simplification, which does not allow comparison of specific surgical techniques. Due to the long-time span of the study, the operations were carried out by several surgeons and personal preferences may have had an influence on the selection of the surgical strategy. Specific complications were reported but no grading scale was employed to assess their severity. The operative techniques have also evolved and the introduction of image-guided intraoperative navigation may have led to an increasing preference towards surgical treatment and especially posterior or combined instrumentations. Another considerable limitation caused by the retrospective setup is the variation in the follow-up and imaging protocols as well as a limited availability of MRI at the beginning of the study period. The morphology of the injury was reviewed and cross-checked by two authors but the possibility of mismatch still exists especially in the evaluation of the facet component. MRI was not available for all patients especially at the early stages of the

Table 7
Characteristics of patients with postoperative failure of fixation ($n = 8$).

Age (years), Gender	AS or DISH	Preoperative AIS grade	AIS grade at last follow-up	AOSpine classification	Surgical approach	Intrumentations	Time from primary surgery to reoperation (days)	Identified events predisposing to failure of fixation
40, M	no	D	D	C6–C7: C (F4 BL)	anterior	cage + plate	14	Ground level fall during the postoperative recovery period
41, M	AS	A	B	C5–C6: C (F4 BL)	anterior	cage + plate	268	–
51, M	DISH	D	E	C6–C7: C (F4 BL)	anterior	cage + plate	133	–
61, M	AS	B	*	C6–C7: C (F4 BL)	anterior	cage + plate	70	A combined surgical approach was planned, but prone position not tolerated
78, M	no	D	D	C6–C7: C (F4 BL)	anterior	cage + plate	78	Osteoporotic bone structure, insufficient hold in one locking screw of the plate
79, M	no	no SCI	no SCI	C6: A4 (C6–C7: F4 BL)	anterior	VBS	29	–
83, F	no	D	C	C6–C7: C (F4 BL) and C7: A3	anterior	plate	14	VBS was planned, but it did not fit
86, M	no	no SCI	*	C5-6-7: B2 (F2)	anterior	cage + plate	53	2-level fixation was planned, but one cage did not fit due to severe degeneration

M, male; F, female; AS, ankylosing spondylitis; DISH, diffuse idiopathic skeletal hyperostosis; AIS, American Spinal Injury Association Impairment Scale; BL, bilateral (facet injuries); VBS, vertebral body substitute; SCI, spinal cord injury; *missing data.

study period. However, in modern decision making on the treatment of subaxial spine injuries the crucial role of MRI is acknowledged.

5. Conclusions

Surgical treatment of SCSIs is safe and provides good results. The surgical approach did not affect the outcome of surgery, but the different approaches had individual complication profiles. Thus, we recommend the surgical approach to be based on a patient- and injury-specific decision. Due to our retrospective setting, no superiority of a surgical approach over another could be demonstrated. Considering its less invasive nature, the anterior approach is recommendable as a primary option. In translation injuries with bilateral facet dislocation a posterior or a combined approach should be considered especially if the dislocation cannot be reduced, and for patients with AS or DISH a posterior or a combined approach is the treatment of choice.

CRediT authorship contribution statement

Joel Alve: Data curation, Investigation, Methodology, Writing – original draft, Visualization. **Jukka Huttunen:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration. **Ville Leinonen:** Conceptualization, Project administration, Resources, Supervision. **Henna-Kaisa Jyrkkänen:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision. **Nils Danner:** Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors have no conflicts of interest. This study was approved by the Ethics Committee of KUH District, Kuopio, Finland (permission number 236/2017). Due to the retrospective nature of the study no informed consent was required.

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Abbreviations

AIS	American Spinal Injury Association Impairment Scale
AS	ankylosing spondylitis
DISH	diffuse idiopathic skeletal hyperostosis
SCI	spinal cord injury
SCSI	subaxial cervical spine injury

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