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Open spinal endoscopy versus microscope-assisted anterior cervical discectomy and fusion for single-segment cervical spondylotic myelopathy: a retrospective comparative study focusing on hidden blood loss and prevertebral soft tissue swelling

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Research Article

Keywords: Cervical spondylotic myelopathy, Open spinal endoscope, Microscope, Anterior cervical discectomy and fusion, Hidden blood loss, Prevertebral soft tissue swelling

Posted Date: June 19th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9738426/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

Anterior cervical discectomy and fusion (ACDF) is the classic surgical procedure for the treatment of cervical spondylotic myelopathy (CSM). In recent years, microscope-assisted ACDF (Micro-ACDF) and open spinal endoscope-assisted ACDF (OSE-ACDF) have been successively applied in clinical practice, effectively improving the precision and minimally invasive nature of decompression. However, there remains a lack of sufficient comparative evidence regarding the differences between these two minimally invasive techniques in perioperative refined parameters, particularly hidden blood loss (HBL) and the degree of prevertebral soft tissue swelling (PSTS). This study aimed to compare the short-term clinical efficacy and perioperative safety of OSE-ACDF and Micro-ACDF in the treatment of single-segment CSM.

Methods

The clinical and radiological data of patients with single-segment CSM who underwent ACDF were retrospectively analyzed. Based on the different intraoperative assisting devices, the patients were divided into the OSE-ACDF group and the Micro-ACDF group. The operation time, intraoperative overt blood loss, and postoperative drainage volume were recorded and compared between the two groups, and the total blood loss and HBL were subsequently calculated. The Japanese Orthopaedic Association (JOA) score, Neck Disability Index (NDI), and Visual Analogue Scale (VAS) were utilized to evaluate the improvement in neurological function and pain alleviation. The degree of PSTS at the C2-C6 levels was radiologically assessed preoperatively and at 2–3 days postoperatively.

Results

Both groups successfully completed the surgeries and were completely followed up. The mean operation time in the OSE-ACDF group was slightly longer than that in the Micro-ACDF group ($P < 0.05$). Regarding blood loss control, although there were no significant differences in intraoperative overt blood loss and postoperative drainage volume between the two groups, the total blood loss and HBL in the OSE-ACDF group were significantly lower than those in the Micro-ACDF group ($P < 0.05$). In terms of clinical efficacy, the JOA, NDI, and VAS scores of both groups at the final follow-up were significantly improved compared with preoperative values, showing no significant intergroup differences ($P > 0.05$). However, in the early postoperative period (3 days postoperatively), the neck VAS score and NDI in the OSE-ACDF group were significantly lower than those in the Micro-ACDF group ($P < 0.001$). Furthermore, radiological measurements indicated that the Micro-ACDF group exhibited significantly more severe prevertebral soft tissue swelling (ΔPSTS) at the C4 segments ($P < 0.05$), which corresponded to a higher incidence of early postoperative dysphagia.

Conclusion

Both OSE-ACDF and Micro-ACDF demonstrate definite clinical and radiological efficacy in the treatment of single-segment CSM, with comparable safety profiles. Benefiting from continuous aqueous medium irrigation and endoscopic radiofrequency hemostasis techniques, OSE-ACDF exhibits unique advantages in controlling HBL without increasing the risk of PSTS, making it an excellent alternative for implementing minimally invasive ACDF in clinical practice.

Background

Cervical spondylotic myelopathy (CSM) is a common degenerative disease causing progressive neurological impairment in middle-aged and elderly populations[1]. Since Smith and Robinson established anterior cervical discectomy and fusion (ACDF) in the 1950s, this technique has become the standard treatment strategy for single-level CSM due to its advantages in directly relieving ventral compression and reconstructing cervical alignment[2]. However, during the establishment of the surgical corridor in traditional open ACDF, extensive dissection and prolonged physical retraction of the anterior cervical muscles, neurovascular sheath, trachea, and esophagus are required. Such mechanical load is highly prone to inducing early postoperative prevertebral soft tissue swelling (PSTS), which subsequently leads to complications such as dysphagia or airway obstruction. This not only prolongs the length of hospital stay but also significantly diminishes the early postoperative recovery experience, contradicting the current concept of enhanced recovery after surgery (ERAS)[3,4].

To overcome the inherent limitations of traditional open procedures, minimally invasive techniques such as microscope-assisted ACDF (Micro-ACDF) and the emerging one-hole split endoscopic ACDF (OSE-ACDF) have been developed. Theoretically, owing to a narrower working channel and refined manipulation, OSE-ACDF holds the potential to further alleviate soft tissue retraction and reduce the risk of PSTS compared to Micro-ACDF. However, a paucity of systematic comparative evidence remains regarding the efficacy of these two minimally invasive modalities in mitigating early postoperative complications. Therefore, this study aimed to retrospectively analyze the clinical and radiological data of patients with single-level CSM treated with either OSE-ACDF or Micro-ACDF at our institution. Beyond comparing the routine clinical outcomes between the two cohorts, this study specifically quantified the severity of early postoperative PSTS and the incidence of dysphagia, while pioneering the application of a multivariate regression analysis model[5,6]. The objective was to isolate the independent risk factors for these early complications, thereby providing spine surgeons with robust, evidence-based guidance for the selection of minimally invasive equipment and the formulation of refined perioperative management strategies.

Data and methods

Study design and patient population

This was a single-center, retrospective cohort study. The study protocol strictly adhered to the ethical principles of the Declaration of Helsinki and was approved by the Independent Clinical Research Ethics Committee of our institution. Informed consent for surgery and the use of clinical data was obtained from all included patients.

The inclusion criteria were as follows: (1) a definitive diagnosis of single-level CSM with ventral spinal cord compression, confirmed by a detailed medical history, physical examination, and radiological evaluation (MRI/CT); (2) no substantial improvement or progressive exacerbation of neurological impairment symptoms following systematic conservative treatment for more than 6 weeks; (3) patients who underwent either OSE-ACDF or Micro-ACDF (depending on the intraoperative assistive devices utilized), with cervical reconstruction completed using a stand-alone interbody fusion cage, such as a zero-profile device.

The exclusion criteria were as follows: (1) multi-level CSM involving two or more (≥ 2) symptomatic segments, or concurrent severe ossification of the posterior longitudinal ligament or ligamentum flavum hypertrophy necessitating posterior decompression; (2) a prior history of cervical spine surgery, definitive cervical trauma, active infection, or local neoplastic lesions; (3) concomitant severe systemic medical conditions, coagulopathy, or an uncontrollable bleeding risk due to the long-term administration of anticoagulant medications.

Surgical techniques

OSE-ACDF

After successful general anesthesia, the patient was placed in a supine position. The posterior neck was elevated to maintain the cervical spine in a slightly hyperextended position. The C5/6 intervertebral space was localized via fluoroscopy, and skin markings were made. Routine disinfection and draping were then performed. A transverse arc-shaped incision of approximately 3 cm in length was made centered on the anterior border of the right sternocleidomastoid (SCM) muscle. The skin, subcutaneous tissue, and platysma were incised sequentially. The skin flaps were mobilized subplatysmally. An anterior approach was established from the right anterior border of the SCM through blunt dissection. The neurovascular sheath was retracted laterally, and the visceral sheath was retracted medially to expose the prevertebral fascia.

The C5/6 intervertebral space was confirmed again via X-ray fluoroscopy, and the spinal endoscope was introduced. Under endoscopic assistance, the C5/6 intervertebral disc was excised. A flat-tipped interbody spreader was utilized to appropriately distract and release the intervertebral space. A 2-mm Kerrison rongeur, combined with a high-speed diamond burr, was used to remove the hyperplastic osteophytes at the posterior margins of the C5 and C6 vertebral bodies. Pituitary rongeurs and curettes were used collaboratively to remove the residual disc tissue. The posterior longitudinal ligament was then incised, revealing severe spinal cord compression and poor local blood supply. A 2-mm Kerrison rongeur and a 3-mm high-speed diamond burr were utilized to further resect the posterior margins of the

C5 and C6 vertebral bodies, as well as the hyperplastic bone of the uncovertebral joints. A nerve hook was used to explore the posterior spinal canal of the C5 and C6 vertebral bodies and the bilateral C6 nerve root canals, confirming adequate decompression of the dura mater and nerve roots with good dural pulsations.

The autologous bone fragments harvested during decompression were packed into an interbody fusion cage, which was then implanted into the C5/6 intervertebral space and tamped into place. A self-locking titanium plate and four screws were selected and securely fixed. After verifying the correct count of gauze and surgical instruments, meticulous hemostasis was achieved. One drainage tube was placed, the endoscope was withdrawn, and the incision was sutured layer by layer. Finally, a sterile dressing was applied (Fig. 1).

Micro-ACDF

The anesthesia, patient positioning, and fluoroscopic localization were identical to those described previously. A transverse arc-shaped incision, approximately 6 cm in length, was made from the mid-portion of the sternocleidomastoid muscle to the anterior midline of the neck. The subsequent exposure steps were the same as those in the OSE group. Self-retaining retractors and a Caspar distractor were then deployed. Following the positioning of the operating microscope, the C5/6 intervertebral disc was excised under microscopic visualization. Hyperplastic osteophytes at the posterior margins of the C5 and C6 vertebral bodies were removed using a combination of 1-mm and 2-mm Kerrison rongeurs. The posterior longitudinal ligament was resected to expose the dura mater, and the hyperplastic bone of the bilateral uncovertebral joints was excised. A nerve hook was utilized to explore the posterior spinal canal of the C5 and C6 vertebral bodies as well as the bilateral C6 nerve root canals, verifying the absence of compression on the dura mater and nerve roots. The autologous bone fragments harvested during decompression were packed into the cage, and the remaining surgical steps were performed identically to the aforementioned procedures (Fig. 2).

Postoperative management

Both groups followed a standardized postoperative rehabilitation protocol. Routine postoperative interventions included the administration of neurotrophic agents and symptomatic non-steroidal anti-inflammatory drugs (NSAIDs). The drainage tube was removed when the drainage volume was less than 30 mL per 24 hours. Patients were encouraged to initiate early ambulation on postoperative day 1 under the strict protection of a cervical collar, which was maintained for 6 to 8 weeks.

Outcome measures

Quantitative indicators of early complications

Prevertebral soft tissue swelling (PSTS): PSTS was independently measured in a double-blind manner by two orthopedic surgeons who were not involved in the surgeries. The measurements were based on standard lateral cervical radiographs taken preoperatively and at 2 to 3 days postoperatively. PSTS was defined as the absolute horizontal distance from the anteroinferior margin of the target vertebral bodies (C2-C6) to the posterior margin of the tracheal air shadow (measured in millimeters) (Fig. 3). The average of the measurements obtained by the two surgeons was ultimately utilized to minimize inter-observer systematic error.

Incidence of dysphagia: Sequential evaluations were performed at 2 to 3 days, 1 week, and 1 month postoperatively based on the Bazaz dysphagia scoring system. Dysphagia was categorized into none (0 points), mild (difficulty limited to dry or hard solid foods), moderate (difficulty with soft foods), and severe (difficulty even with liquids).

Perioperative and hidden blood loss parameters

The total operative time, intraoperative visible blood loss, and postoperative drainage volume were meticulously recorded. Based on the patients' hematocrit (Hct) levels preoperatively and on postoperative day 2, the Nadler formula was utilized to estimate the patient's blood volume (PBV). Subsequently, the Gross equation was applied to accurately calculate the total blood loss (TBL) and hidden blood loss (HBL). Additionally, neurological functional recovery and pain relief were evaluated at baseline and at each postoperative follow-up time point using the Japanese Orthopaedic Association (JOA) score, the Neck Disability Index (NDI), and the Visual Analog Scale (VAS).

Statistical analysis

All quantitative data cleaning and model construction were performed using SPSS version 27.0 software. The normality of continuous variables was initially evaluated using the Shapiro-Wilk test. Normally distributed continuous data were expressed as the mean ± standard deviation (SD), and inter-group comparisons were conducted using the independent-samples t-test (Welch's t-test correction was applied when variances were unequal). Non-normally distributed continuous data were presented as the median and interquartile range, and analyzed using the Mann-Whitney U test. Categorical variables were expressed as frequencies and percentages (n, %), and comparisons of incidence rates between groups were performed using Pearson's chi-square test. When the theoretical frequency in any cell was less than 5, Fisher's exact test was utilized instead (e.g., for comparing the incidence of dysphagia at 1 month postoperatively). Inter-group differences for ordinal data (e.g., the Bazaz severity grading of dysphagia) were analyzed using the non-parametric Mann-Whitney U test (rank-sum test). To isolate confounding factors and identify the independent risk factors for early postoperative dysphagia, variables demonstrating potential clinical significance in the univariate analysis were incorporated into a multivariate logistic regression model, with the calculation of odds ratios and 95% confidence intervals. All hypothesis tests were two-sided, and a $P < 0.05$ was considered to indicate a statistically significant difference.

Results

Baseline characteristics

A total of 70 patients with single-level CSM who met the inclusion and exclusion criteria were ultimately included in this study. Among them, 35 patients underwent OSE-ACDF, and 35 underwent Micro-ACDF. The two groups exhibited high homogeneity in terms of demographic characteristics (including mean age, sex distribution, and body mass index [BMI]) and disease duration ($P > 0.05$), confirming the excellent comparability between the two cohorts (Table 1).

Table 1
Patient Demographics and Baseline Characteristics

Variables	**OSE-ACDF Group (n = 35)**	**Micro-ACDF Group (n = 35)**	***P* Value**
Age (years)	56.26 ± 9.62	54.17 ± 10.06	0.378
Gender (Male/Female)	11/24	9/26	0.597
BMI (kg/m²)	24.15 ± 3.74	24.57 ± 4.55	0.677
Smoking history, n (%)	13(37.14)	15(42.86)	0.626
Diabetes mellitus, n (%)	7(20.00)	9(25.71)	0.569
Operated segment, n			0.410
C2/3	4	1	
C3/4	7	11	
C4/5	17	15	
C5/6	7	8	

Perioperative parameters

Regarding the core perioperative parameters, the two minimally invasive assistive technologies exhibited distinct technical characteristics. Analysis indicated that the surgical incision length in the OSE-ACDF group was significantly shorter than that in the Micro-ACDF group ($P < 0.05$). Due to the specificities of operations within a water medium and the coordination of endoscopic instruments, the mean operative time in the OSE-ACDF group was slightly longer than that in the Micro-ACDF group ($P < 0.05$).

In terms of blood conservation, although there were no statistically significant differences between the two groups regarding intraoperative visible blood loss and 24-hour postoperative drainage volume ($P > 0.05$), calculations utilizing the equations revealed that both the TBL and HBL in the OSE-ACDF group were significantly lower than those in the Micro-ACDF group ($P < 0.01$). The mean length of postoperative hospital stay was comparable between the two groups (**Table 2**).

Table 2 Comparison of Perioperative Blood Loss between the Two			
Variables	OSE-ACDF Group (n = 35)	Micro-ACDF Group (n = 35)	*P* Value
Hematological parameters			
PBV (mL)	4257.99 ± 522.05	4291.51 ± 545.14	0.794
Preoperative Hct (%)	41.39 ± 3.16	41.18 ± 3.23	0.783
Postoperative day 2 Hct (%)	40.67 ± 3.13	39.06 ± 2.87	0.028*
Visible blood loss (mL)			
Intraoperative blood loss	21.75 ± 6.51	21.04 ± 7.10	0.667
Postoperative drainage	14.73 ± 5.93	15.38 ± 6.34	0.660
Calculated blood loss (mL)			
TBL	72.92 ± 12.20	216.70 ± 22.45	0.001*
HBL	36.44 ± 7.62	180.27 ± 18.56	0.001*

Clinical and radiographic outcomes

All patients completed sequential follow-ups (mean follow-up, 14.2 months). There were no statistically significant differences in the baseline comparisons of the core clinical scales (JOA, VAS, and NDI scores) between the two groups preoperatively ($P > 0.05$). Intra-group longitudinal comparisons revealed that the VAS scores for the extremities and the JOA scores in both groups were highly significantly improved at all postoperative follow-up time points compared with the preoperative baselines ($P < 0.001$).

Regarding the indicators reflecting surgical approach trauma, the OSE-ACDF group demonstrated a highly significant advantage in early recovery: at 3 days postoperatively, the neck VAS score and NDI index in the OSE-ACDF group were significantly lower than those in the Micro-ACDF group ($P < 0.001$). With the gradual healing of the surgical trauma, the neck pain and functional impairment in both groups decreased to extremely low levels by 3 months postoperatively and at the final follow-up, with the early inter-group differences subsequently disappearing ($P > 0.05$) (Table 3).

In terms of the efficacy of nerve root and spinal cord decompression, intra-group horizontal comparisons indicated that the VAS scores for the extremities and JOA scores at all postoperative follow-up time points were highly significantly improved compared to preoperative values in both groups ($P < 0.001$). At 3 days and 3 months postoperatively, there were no statistical differences in the extremity VAS and JOA scores between the two groups ($P > 0.05$), confirming that the endoscopic technique possesses equivalent excellent neural decompression efficacy to the microscope; by 12 months postoperatively, the

long-term radiating pain in the extremities in the OSE group even demonstrated a further slight statistical advantage ($P < 0.01$).

Radiographic tracking demonstrated that the physiological cervical curvature and the height of the fused segments were effectively reconstructed postoperatively in both groups. Furthermore, solid bony fusion was confirmed within 6 to 12 months postoperatively in all cases, without any observed complications such as subsidence or migration of the internal fixation (Figs. 4 and 5).

Table 3
Comparison of VAS Scores between the Two Surgical Procedures

Parameters	**OSE group (n = 35)**	**Micro group (n = 35)**	***P* value**
Neck VAS score (points, mean ± SD)			
Preoperative	6.51 ± 0.83	6.53 ± 0.80	0.895
Postoperative 3 days	2.26 ± 0.44	6.03 ± 0.79	<0.001*
Postoperative 3 months	1.09 ± 0.36	1.16 ± 0.41	0.445
Postoperative 12 months	0.67 ± 0.29	0.61 ± 0.28	0.357
P value	< 0.001*	< 0.001*	
Limb VAS score (points, mean ± SD)			
Preoperative	7.16 ± 0.98	7.56 ± 0.73	0.061
Postoperative 3 days	1.49 ± 0.70	1.46 ± 0.74	0.869
Postoperative 3 months	0.74 ± 0.38	0.91 ± 0.37	0.057
Postoperative 12 months	0.50 ± 0.36	0.56 ± 0.33	0.444
P value	< 0.001*	< 0.001*	
NDI (%, mean ± SD)			
Preoperative	45.00 ± 4.96	44.97 ± 5.68	0.984
Postoperative 3 days	25.69 ± 2.67	61.50 ± 3.29	<0.001*
Postoperative 3 months	11.71 ± 2.90	12.25 ± 2.61	0.412
Postoperative 12 months	8.05 ± 2.40	7.82 ± 1.36	0.616
P value	< 0.001*	< 0.001*	
JOA score (points, mean ± SD)			
Preoperative	12.63 ± 1.56	12.54 ± 1.65	0.824
Postoperative 3 days	14.06 ± 1.51	14.17 ± 1.56	0.757
Postoperative 3 months	14.94 ± 1.53	15.09 ± 1.62	0.706
Postoperative 12 months	15.31 ± 1.45	15.43 ± 1.58	0.753
P value	< 0.001*	< 0.001*	

Primary outcomes: PSTS and dysphagia

Incidence of dysphagia: In the early postoperative period (2 to 3 days), 20.0% (7/35) and 54.3% (19/35) of patients in the OSE-ACDF and Micro-ACDF groups, respectively, experienced varying degrees of

dysphagia. Based on the Bazaz scoring system, the vast majority of these cases were classified as mild to moderate. At the 1-month postoperative follow-up, the dysphagia symptoms had completely resolved in all patients, with no significant differences observed in the incidence or severity distribution between the two groups ($P > 0.05$) (Table 3).

Table 3
Incidence and Severity of Postoperative Dysphagia (Bazaz Score)

Dysphagia Severity (Bazaz)	**OSE-ACDF Group (n = 35)**	**Micro-ACDF Group (n = 35)**	***P* Value**
Early Postoperative			0.003*
None (0)	28	16	
Mild (1)	6	14	
Moderate (2)	1	4	
Severe (3)	0	1	
Total Incidence, n (%)	7 (20.0%)	19 (54.3%)	
1-Month Postoperative			0.428
None (0)	33	30	
Mild (1)	2	4	
Moderate (2)	0	1	
Severe (3)	0	0	
Total Incidence, n (%)	2 (5.7%)	5 (14.3%)	

Radiographic measurement results (Table 4) demonstrated that the baseline preoperative PSTS thickness at each cervical level (C2–C6) was highly comparable between the two groups ($P > 0.05$). In the early postoperative period, both groups exhibited varying degrees of soft tissue widening. Inter-group comparisons revealed no statistically significant differences between the OSE-ACDF and Micro-ACDF groups regarding the absolute postoperative thickness and the change in thickness (ΔPSTS) at the C2, C3, and C5 levels. This finding confirms that continuous endoscopic water irrigation did not impose an additional volumetric burden on the overall prevertebral soft tissue.

However, the extent of local swelling at the C4 and C6 levels was significantly greater in the Micro-ACDF group compared to the OSE-ACDF group. Specifically, the increment in swelling at the C4 level was most pronounced in the Micro-ACDF group (4.60 ± 2.13 mm vs. 3.30 ± 2.13 mm, $P = 0.013$). Considering that the C4 segment is anatomically situated at the critical chokepoint of swallowing biomechanics, this significant localized soft tissue widening is closely associated with the high incidence of early postoperative dysphagia. Furthermore, the Micro-ACDF group also exhibited significant excessive swelling at the C6 segment (ΔC6: 2.80 ± 1.32 mm vs. 1.40 ± 1.32 mm, $P = 0.001$). This finding strongly

indicates a pathological process wherein excessive intraoperative hidden blood loss accumulates caudally along the prevertebral fascial spaces under the influence of gravity.

Table 4
Radiographic Prevertebral Soft Tissue Swelling (PSTS) Measurements

Variables	OSE-ACDF Group (n = 35)	Micro-ACDF Group (n = 35)	*P* Value
Preop PSTS(mm)			
C2	4.17 ± 1.07	4.23 ± 0.73	0.799
C3	4.42 ± 0.68	4.58 ± 0.91	0.385
C4	6.06 ± 1.30	5.94 ± 1.13	0.672
C5	12.18 ± 2.12	11.82 ± 1.91	0.448
C6	12.15 ± 2.23	12.25 ± 2.23	0.841
Postop PSTS(mm)			
C2	6.43 ± 1.93	6.67 ± 1.64	0.576
C3	8.14 ± 2.52	8.46 ± 2.15	0.565
C4	9.36 ± 2.28	10.54 ± 2.52	0.045*
C5	14.65 ± 2.75	14.35 ± 2.48	0.636
C6	13.55 ± 2.53	15.05 ± 2.59	0.017*
ΔPSTS (Postop - Preop, mm)			
ΔC2	2.26 ± 1.46	2.44 ± 1.57	0.614
ΔC3	3.72 ± 2.31	3.88 ± 1.70	0.749
ΔC4	3.30 ± 2.13	4.60 ± 2.13	0.013*
ΔC5	2.46 ± 1.60	2.54 ± 2.03	0.872
ΔC6	1.40 ± 1.32	2.80 ± 1.32	0.001*

Risk factors analysis

To isolate confounding factors and investigate the core variables influencing early postoperative dysphagia, a multivariate logistic regression model was implemented in this study. The occurrence of early postoperative dysphagia (Bazaz score ≥ 1) was designated as the binary dependent variable. Following preliminary univariate analysis and the exclusion of high multicollinearity via collinearity diagnostics, variables including age, operative time, HBL, ΔPSTS at C4, and surgical modality (OSE-ACDF vs. Micro-ACDF) were incorporated into the final multivariate regression equation (Table 5).

The results demonstrated that an increase in HBL (OR = 1.231, 95% CI: 1.029–1.473, *P* = 0.023) and a more pronounced soft tissue swelling at the C4 segment (ΔPSTS at C4) (OR = 20.805, 95% CI: 1.243–348.164, *P* = 0.035) were independent risk factors triggering early postoperative dysphagia. Notably, after controlling for core mediating variables such as hemorrhage and swelling, the choice of minimally invasive surgical modality (endoscopic or microscopic group) per se was not an independent influencing factor for dysphagia (*P* = 0.444).

Table 5
Multivariate Logistic Regression Analysis for Risk Factors of Early Postoperative Dysphagia

Variables	**B**	**S.E.**	**Wald**	***P* Value**	**Odds Ratio (95% CI)**
Age	-0.059	0.122	0.235	0.628	0.942 (0.741–1.198)
Operative time	0.038	0.057	0.442	0.506	1.038 (0.929–1.161)
Group (Micro-ACDF)	3.15	4.116	0.585	0.444	23.328 (0.007–74403.38)
Hidden blood loss (HBL)	0.208	0.092	5.15	0.023*	1.231 (1.029–1.473)
ΔPSTS at C4	3.035	1.438	4.458	0.035*	20.805 (1.243–348.164)

Discussion

To avoid iatrogenic injuries associated with traditional open approaches, surgical treatment for CSM has gradually evolved toward minimally invasive techniques. Although the Micro-ACDF technique pioneered by Hankinson et al. in 1975 enhanced surgical safety by providing magnified stereoscopic vision, its deep illumination is often limited by bony structures, and surgeons cannot completely eliminate the continuous physical retraction of the visceral sheath by automatic retractors[7,8]. In recent years, OSE-ACDF has entered clinical practice, boasting significant advantages such as a wide-angle field of view, water-medium irrigation, and precise endoscopic radiofrequency hemostasis in situ[9,10]. However, there is a paucity of systematic, evidence-based data regarding the comparative efficacy of these two minimally invasive modalities in controlling early postoperative complications. Through a retrospective sequence analysis, this study found that the OSE-ACDF and Micro-ACDF groups were largely comparable in terms of the degree of early postoperative PSTS widening and the incidence of dysphagia. Crucially, the multivariate regression model in this study revealed a highly significant clinical phenomenon: HBL, rather than the surgical modality itself, is the independent risk factor for inducing early postoperative PSTS and dysphagia.

This finding prompted us to re-examine the soft tissue protective effects of the two minimally invasive techniques from the underlying logic of their surgical mechanisms. In Micro-ACDF, to obtain an adequate deep field of view, prolonged static retraction of the trachea and esophagus by self-retaining retractors is inevitable, which is highly prone to causing local microcirculatory disturbances and postoperative rebound congestive edema[8]. In contrast, OSE-ACDF achieves an innovative "stealthy decompression" effect. The 30-degree wide viewing angle of the endoscopic system allows direct penetration into the

narrow intervertebral space for multi-angle exploration. This "inside-out" observational mode enables the surgeon to accomplish thorough resection of the bilateral uncovertebral joints and osteophytes without the need for excessive incision enlargement or deep soft tissue retraction[11]. Such refined physical protection of the structural integrity of the anterior cervical visceral sheath effectively shortens the plateau phase of soft tissue swelling[12].

Although OSE-ACDF possesses a significant advantage in eliminating continuous mechanical retraction, its unique "water medium" environment has sparked a new clinical paradox: whether continuous fluid pressure would propel the irrigation fluid to leak along the anterior cervical fascial spaces, thereby exacerbating local fluid accumulation or PSTS[13]. The results of this study did not demonstrate an exacerbation of PSTS in the OSE-ACDF group, which is attributable to underlying multiple compensatory and protective mechanisms. First, OSE-ACDF adopts an "open" drainage pathway by incising the annulus fibrosus to the medial border of the longus colli muscles, allowing the irrigation fluid to flow out naturally and preventing the formation of high local pressure. Second, the physical cooling effect of the water medium significantly counteracts the thermal conduction injury generated by high-speed burrs or radiofrequency, mitigating reactive inflammation of the soft tissues[14]. More centrally, by reducing HBL, endoscopic surgery completely offsets the potential negative impacts of water pressure from a pathophysiological perspective. The high-resolution field of view and hydraulic barrier under endoscopy, combined with radiofrequency electrodes, achieve highly efficient in situ hemostasis[15]. HBL, which has often been neglected in previous studies, is actually a crucial predictive factor for triggering early complications[16]. Compared to the hemolytic reaction caused by the extravasation of red blood cells into the interstitial spaces during microscopic surgery, the strict control of HBL by OSE-ACDF substantially reduces the release of inflammatory mediators (such as IL-1, IL-6, etc.), thereby blocking the chemotaxis-induced osmotic tissue edema at its source[17].

Although this study provided an in-depth analysis of the influencing factors for PSTS and its related complications through a multivariate model, certain limitations remain. First, due to the constraints of the retrospective study design, we were unable to quantify the negative pressure values of the intraoperative suction and the exact dynamic flow rate of the irrigation fluid; these hydrodynamic parameters may exert subtle interferences on the final outcomes. Second, the evaluation of PSTS in this study primarily relied on lateral cervical X-ray measurements. Future studies should consider incorporating ultrasound or MRI diffusion-weighted imaging techniques to more accurately differentiate between early inflammatory edema and local hematoma formation. Furthermore, given the single-center sample design of this study, the conclusions still require further validation through future multicenter, large-sample, prospective randomized controlled trials.

Conclusion

Both OSE-ACDF and Micro-ACDF demonstrate definitive and comparable mid- to long-term clinical efficacy in the treatment of single-level CSM. However, OSE-ACDF presents a significant advantage in

optimizing early postoperative rehabilitation. This study confirms that the effective management of HBL is crucial for preventing early PSTS and subsequent dysphagia. Through the concept of "stealthy decompression," OSE-ACDF minimizes mechanical retraction, while its precise radiofrequency hemostasis in a water medium substantially reduces HBL. By circumventing the pathological pathways leading to local inflammatory edema without increasing soft tissue burden, OSE-ACDF aligns optimally with the principles of ERAS and emerges as a highly promising minimally invasive alternative.

Abbreviations

CSM	Cervical spondylotic myelopathy
ACDF	Anterior cervical discectomy and fusion
PSTS	Prevertebral soft tissue swelling
ERAS	Enhanced recovery after surgery
Micro-ACDF	Microscope-assisted ACDF
OSE-ACDF	Open spinal endoscope-assisted ACDF
SCM	Sternocleidomastoid
Hct	Hematocrit
PBV	Patient's blood volume
TBL	Total blood loss
HBL	Hidden blood loss
JOA	Japanese Orthopaedic Association
NDI	Neck disability index
VAS	Visual analog scale
SD	Standard deviation
BMI	Body mass index

Declarations

Ethics approval and consent to participate

We confirm that all methods were carried out in accordance with relevant guidelines and regulations. The research protocol was approved by the Ethics Committee of Binzhou Medical University Hospital on October 15, 2024 (Approval No. KYLL-239). This study strictly followed the ethical principles stated in the 1964 Declaration of Helsinki and its later amendments. Patients were fully informed about the retrospective data collection in advance, and written informed consent was obtained from all participants.

Consent for publication

Not applicable.

Clinical trial number

No applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

No external funding received to conduct this study.

Author contributions

JZ: Study design, literature review, manuscript drafting, and manuscript review. BF and ZX: Critical review of the article's scientific content. XW and LT: Data collection, organization, and statistical analysis. GD and WS: Literature search and case follow-up. PH: Surgical implementation, evaluation, and manuscript review. All authors helped in interpretation of data and critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript.

Acknowledgements

Not applicable.

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Figures

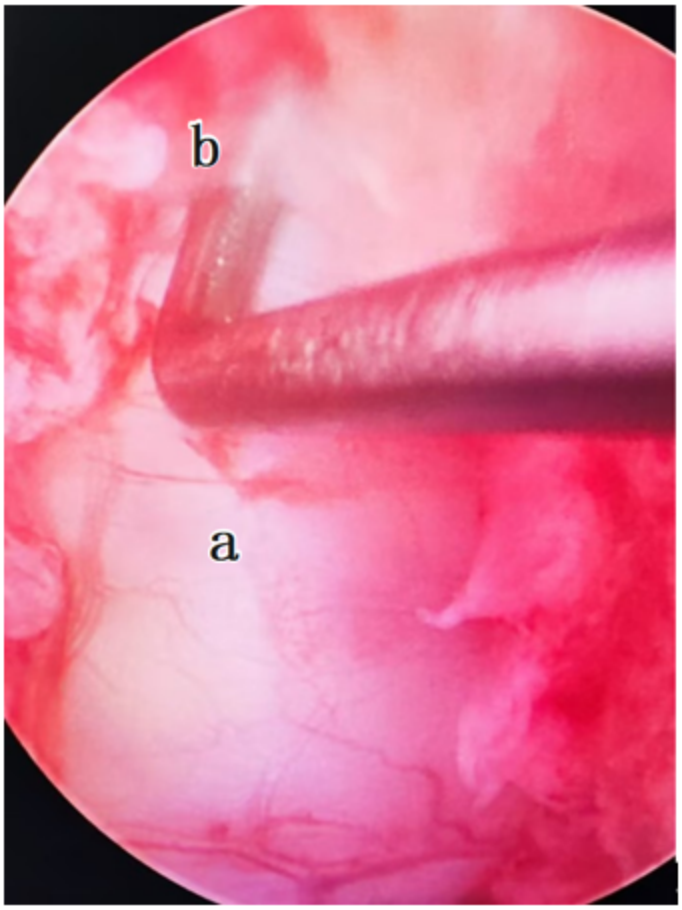


Figure 1

Intraoperative images of OSE-ACDF. a Adequate decompression of the dura mater following the resection of the intervertebral disc, the posterior margins of the vertebral bodies, and the hyperplastic osteophytes of the uncovertebral joints; b Exploration with a nerve hook confirming the patency of the nerve root canals.

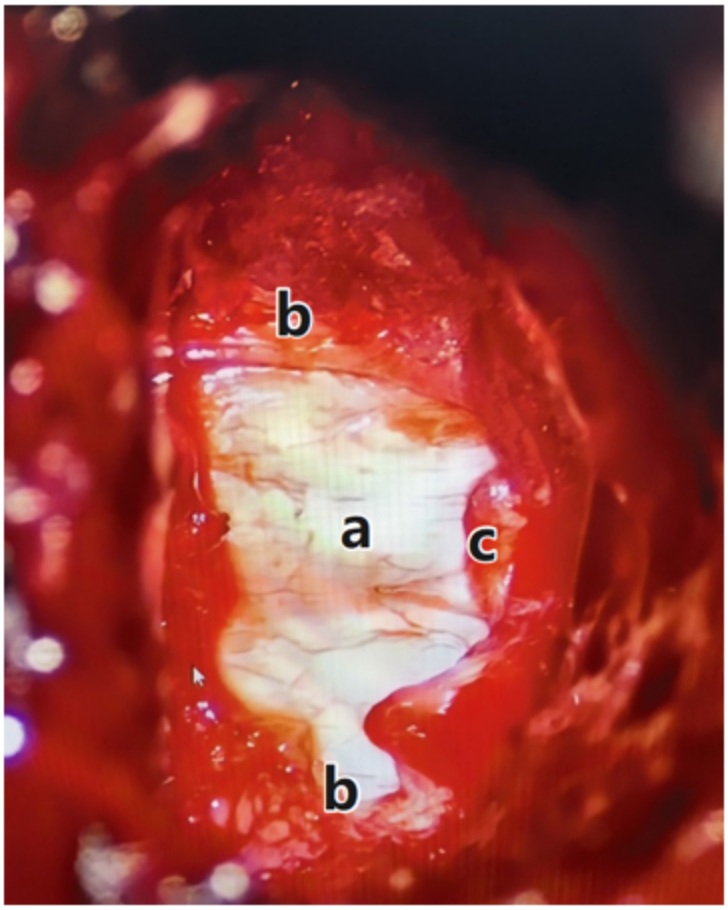


Figure 2

Intraoperative images of Micro-ACDF. a Dura mater; b Nerve root canal; c Remnant of the posterior longitudinal ligament.

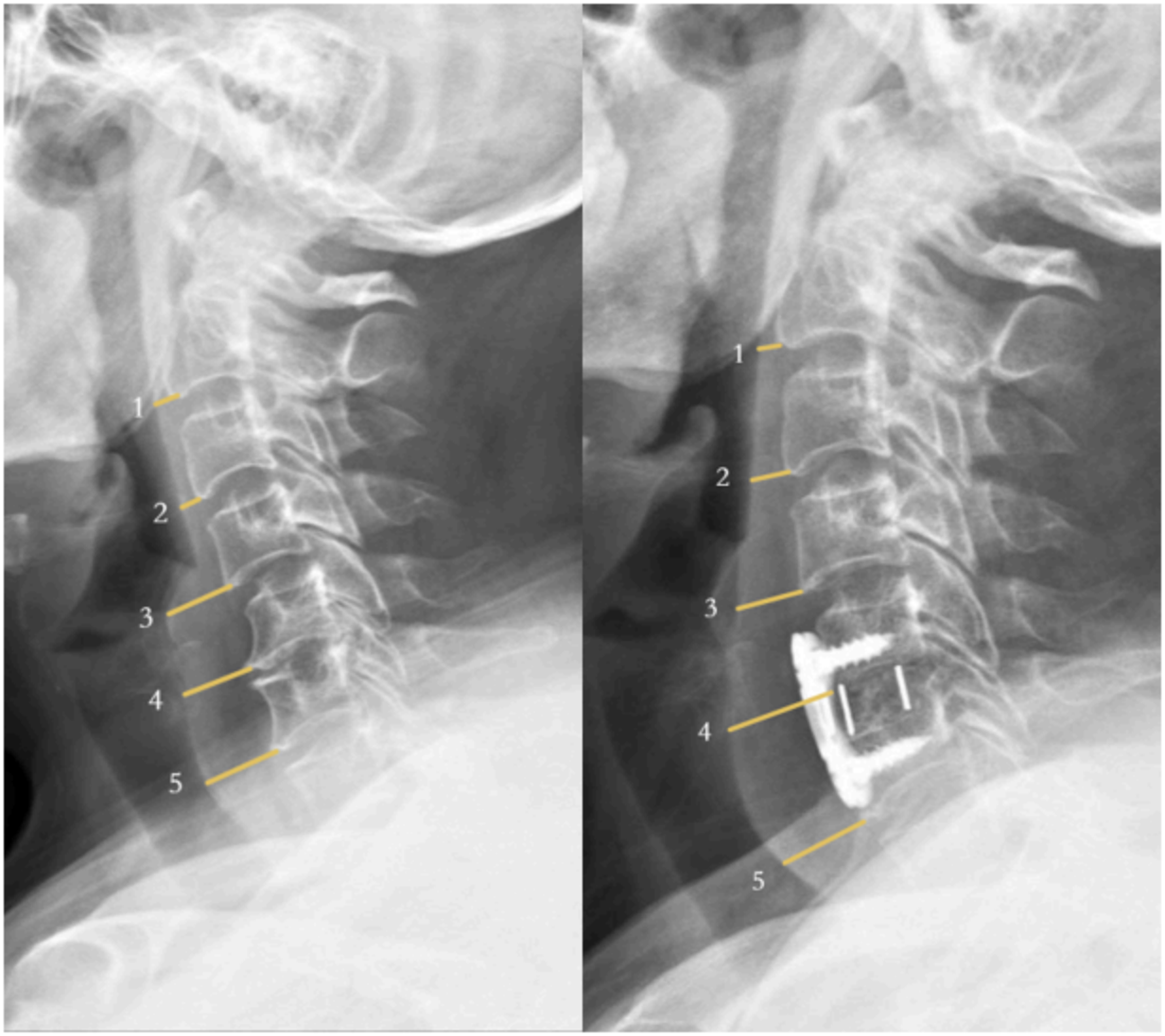


Figure 3

Schematic illustration of the radiographic measurement of the extent of PSTS pre- and postoperatively.

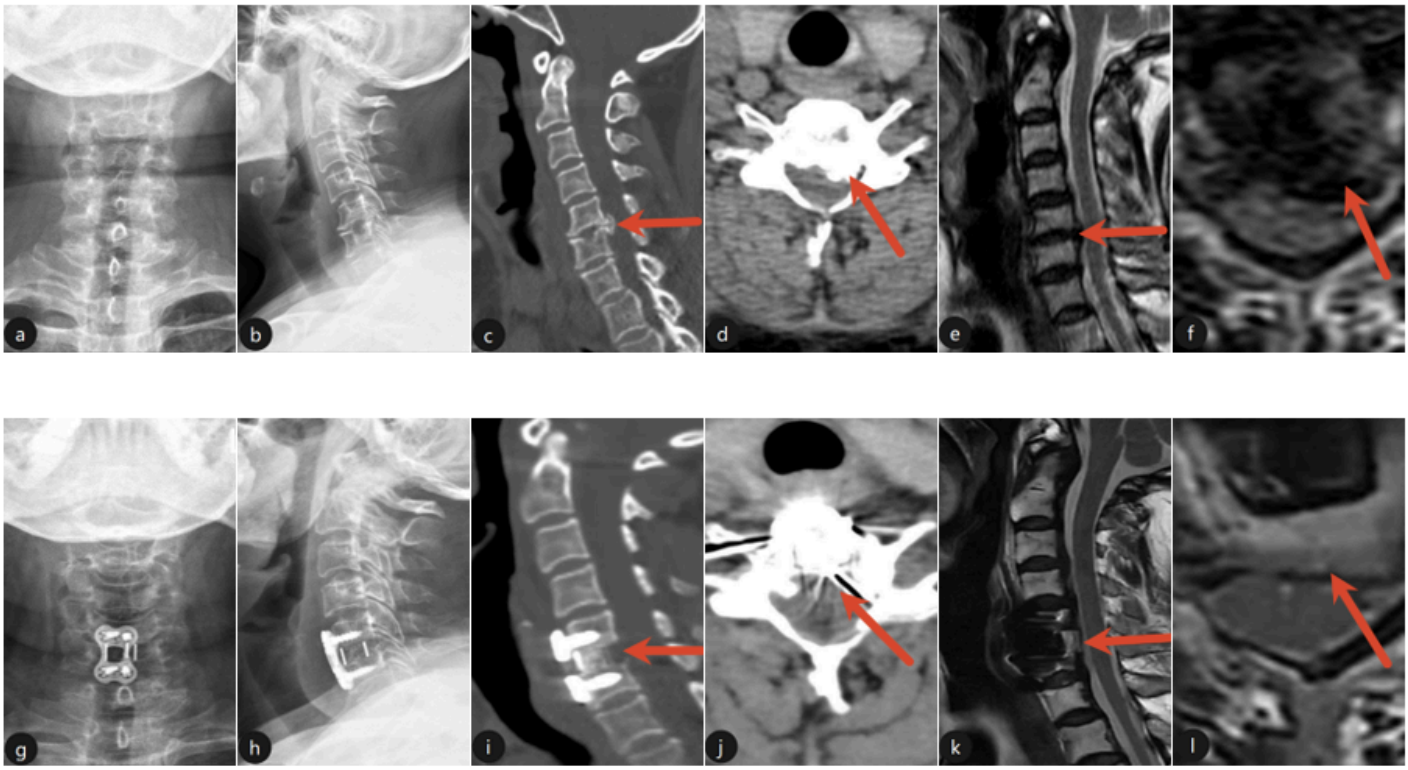


Figure 4

Representative case from the Micro-ACDF group. A 58-year-old female patient presenting with C5-6 CSM. (a, b) Preoperative anteroposterior and lateral radiographs. (c, d) Preoperative sagittal and axial CT scans revealing osteophyte formation at the left posterior margin of the vertebral body (arrows). (e, f) Preoperative sagittal and axial MRI scans displaying disc herniation with resulting anterior spinal cord compression at the responsible segment (arrows). (g–l) Postoperative radiographs, CT, and MRI scans demonstrate excellent positioning of the internal fixation hardware, complete resection of both anterior and posterior vertebral body osteophytes, and significant relief of spinal cord compression (arrows)

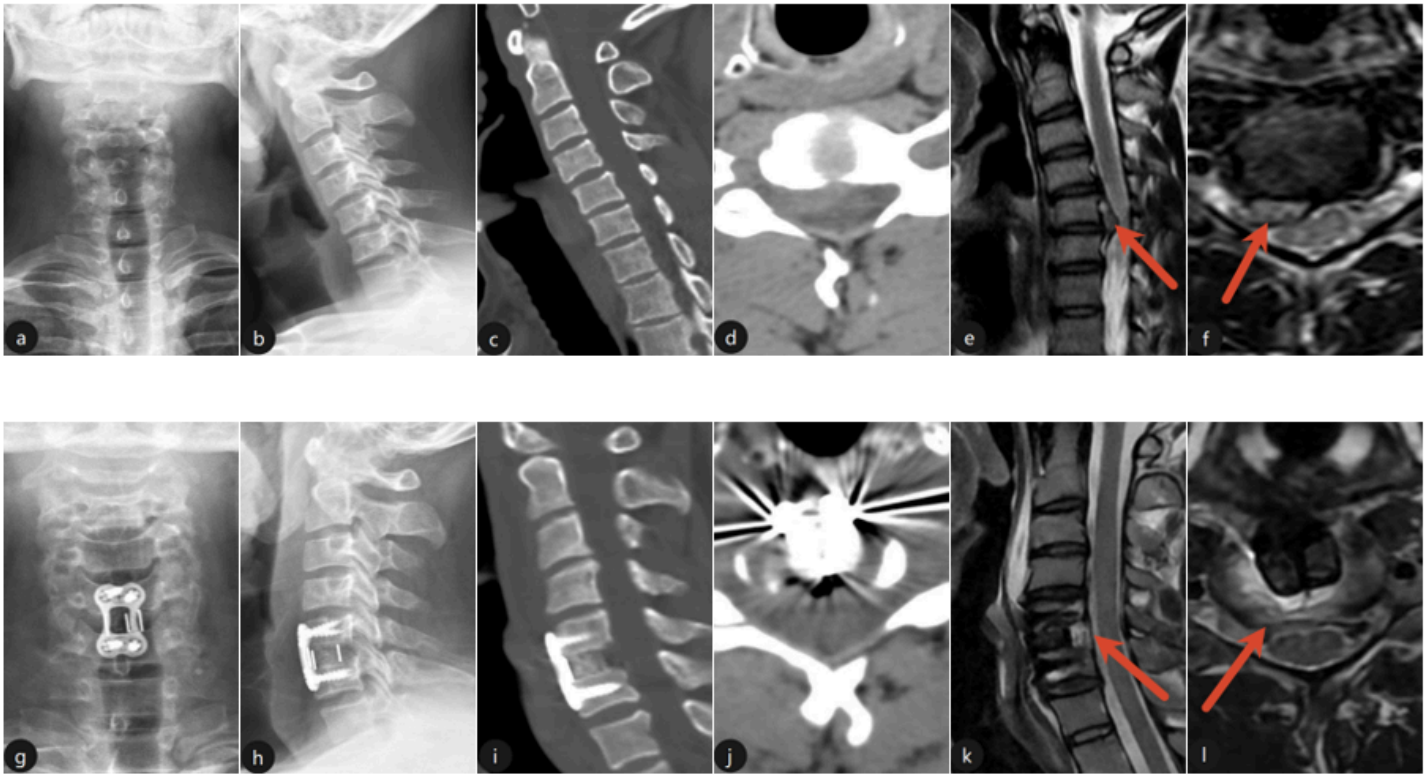


Figure 5

Representative case from the OSE-ACDF group. A 42-year-old male patient presenting with C5-6 CSM. (a, b) Preoperative anteroposterior and lateral radiographs. (c–f) Preoperative sagittal and axial CT and MRI scans displaying a massive right-sided disc herniation at C5/6, with resulting anterior spinal cord compression at the responsible segment (arrows). (g–l) Postoperative radiographs, CT, and MRI scans demonstrate excellent positioning of the internal fixation hardware, complete resection of the herniated disc, and significant relief of spinal cord compression (arrows).