Heliyon 9 (2023) e19106

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Cervical alignment and clinical outcome of anterior cervical discectomy and fusion vs. anterior cervical corpectomy and fusion in local kyphotic cervical spondylotic myelopathy

Wei Du [a], Hai-Xu Wang [a], Jie Lv [b], Shuai Wang [a], Yong Shen [a], Xu Zhang [a], Rong Chen [c,**,1], Li Zhang [a,*,1]

[a] Department of Orthopedics, The Third Hospital of Hebei Medical University, 139 Ziqiang Road, 050051, Shijiazhuang, China
[b] Department of Oral and Maxillofacial Surgery, The Third Hospital of Hebei Medical University, 139 Ziqiang Road, 050051, Shijiazhuang, China
[c] Department of Neurology, Hebei Key Laboratory of Vascular Homeostasis and Hebei Collaborative Innovation Center for Cardio-cerebrovascular Disease, The Second Hospital of Hebei Medical University, 215 Hepingxi Road, 050000, Shijiazhuang, China

ARTICLE INFO

Keywords:
Cervical spondylotic myelopathy
Anterior cervical discectomy and fusion
Anterior cervical corpectomy and fusion
Local kyphosis
Neurological improvement
Axial symptoms

ABSTRACT

Background: Cervical local kyphosis (CLK) is a common degenerative disorder with a potentially debilitating and intractable condition. Currently, there is still debate on the optimal treatment of local kyphotic cervical spondylotic myelopathy (LKCSM) via different anterior approaches.
Objective: The objective of this study was to evaluate the surgical efficacy of anterior cervical discectomy and fusion (ACDF) vs. anterior cervical corpectomy and fusion (ACCF) for the treatment of LKCSM. In addition, the cervical sagittal alignment parameters and axial symptoms (AS) severity after CLK correction were analyzed.
Materials and methods: From January 2016 and December 2020, 104 patients who suffered LKCSM were retrospectively reviewed. These patients underwent ACDF (n = 53) and ACCF (n = 51). Pre- and postoperatively, cervical sagittal alignment parameters were measured on the lateral X-rays, including local kyphotic angles (LKA), C2-7 Cobb angle, T1 slope, and C2-7 sagittal vertical axis (C2-7 SVA). The neurological recovery rate was calculated according to the Japanese Orthopedic Association (JOA) score. The AS severity was evaluated using Neck Disability Index (NDI).
Results: Significant differences ($P < 0.05$) were demonstrated between ACDF and ACCF groups regarding LKA, LKA correction, C2-7 Cobb angle, T1 slope, C2-7 SVA, NDI, NDI recovery and NDI ranking system. However, no significant differences ($P > 0.05$) existed in JOA score, recovery rate, and neurological recovery rate grade. In both groups, significant differences ($P < 0.05$) were demonstrated between pre- and postoperative LKA, T1 slope, C2-7 Cobb angle, C2-7 SVA, JOA score, and NDI. LKA correction showed the positive correlations with the recovery rate ($r = 0.48$, $P < 0.001$), and with the NDI recovery in ACDF group ($r = 0.49$, $P < 0.001$) and in ACCF group ($r = 0.55$, $P < 0.001$).
Conclusions: LKCSM with ≤3 segments of spinal cord compression can be improved with either ACDF or ACCF, resulting in satisfactory neurological outcomes. CLK correction can significantly improve the neurological function and AS, and increase the T1 slope and C2-7 SVA. However, ACDF was more favorable than ACCF in the CLK correction.

* Corresponding author.
** Corresponding author.
E-mail addresses: chenrong52199@126.com (R. Chen), 13933058179@163.com (L. Zhang).
[1] These authors have contributed equally to this work.

https://doi.org/10.1016/j.heliyon.2023.e19106
Received 28 January 2023; Received in revised form 7 August 2023; Accepted 10 August 2023

1. Introduction

Cervical spondylotic myelopathy (CSM) is a chronic degenerative disorder, which often involve the spinal cord compression or ischemia, producing a gradual decrease in neurological function and patient's quality of life. On X-rays, patients with CSM often show cervical local kyphosis (CLK) due to the intervertebral height decrease and sagittal lordotic malalignment, as well as the discs and facet joints degeneration [1]. Major symptoms include neck fatigue, neck pain, myelopathy, radiculopathy, horizontal gaze problems, and swallowing and breathing abnormalities [2]. Non-surgical treatments may limitedly improve the neurological function and cervical sagittal alignment to a certain extent. However, with the deterioration of neurological function, surgery remains to be the most effective strategy for the treatment of local kyphotic cervical spondylotic myelopathy (LKCSM). The surgical goals are still spinal cord decompression, local kyphotic correction, and spinal stabilization with solid bony fusion. CLK is a common degenerative disorder with a potentially debilitating condition, which is treated intractably [3].

In the past decades, anterior approach, including anterior cervical discectomy and fusion (ACDF) and anterior cervical corpectomy and fusion (ACCF), had been demonstrated effectively to improve the clinical outcomes in the treatment of cervical degenerative disease due to radiculopathy and myelopathy [4,5]. Through anterior approach, spinal surgeon can be particularly propitious to decompress the spinal cord, remove anterior bony spurs and disc fragments, restore intervertebral height and correct local kyphosis. Nevertheless, the anterior approach for LKCSM has a high risk of complications, like dysphagia, hoarseness, iatrogenic spinal cord injury, cerebrospinal fluid leakage, pseudarthrosis and graft failure [6,7]. Currently, there was no consensus on the surgical efficacy between ACDF and ACCF for LKCSM. Recently, T1 slope and C2-7 sagittal vertical axis (C2-7 SVA) were proved to be important radiological parameters for evaluating loss of cervical lordosis/kyphosis [8–11]. However, there were few reports on investigating the changes of cervical sagittal alignment parameters after CLK correction.

The objective of this study was retrospectively to evaluate the surgical efficacy of ACDF vs. ACCF for the treatment of LKCSM. In addition, we analyzed the cervical sagittal alignment parameters and axial symptoms (AS) severity after CLK correction.

2. Material and methods

2.1. Participants

From January 2016 and December 2020, a total of 151 patients with LKCSM were retrospectively reviewed at our hospital. In this series, 70 patients underwent ACDF and 81 patients underwent ACCF.

Patient inclusion criteria were as follows: (1) ≤ 3 segments of spinal cord compression with combined symptoms and signs of CSM; and (2) C2-7 Cobb angle $<0^\circ$ on lateral neutral X-ray was defined as kyphosis. The exclusion criteria: (1) cervical trauma or injury ($n = 8$ in ACDF group; $n = 13$ in ACCF group); (2) > 3 segments of ossification of the posterior longitudinal ligament (OPLL); (3) active infection; (4) severe cervical anatomic deformity; (5) tumor ($n = 2$ in ACDF group; $n = 9$ in ACCF group); (6) incomplete or poor-quality images ($n = 3$ in ACDF group; $n = 6$ in ACCF group); (7) loss to follow-up ($n = 4$ in ACDF group; $n = 2$ in ACCF group).

Finally, this study included the remaining 104 patients (53 patients in ACDF group; 51 patients in ACCF group). The research protocol was approved by the Investigational Review Board of The Third Hospital of Hebei Medical University, and signed written informed consents were obtained from all participants prior to the research. The patients in this study consented to publish their images.

2.2. Surgical techniques

As described by Robinson and Smith [12] and Cloward [13], we performed the conventional right-sided transverse incision to expose the surgical segment according to the preoperative planning. In ACDF group, we removed the herniated disc, the posterior longitudinal ligament, and osteophytes. We appropriately distracted the intervertebral space with a Caspar spreader, which kept the intervertebral space wide in the anterior edge and narrow in the posterior edge. We removed the cartilaginous endplates using a curette, and protected the bony endplates simultaneously to prevent cage subsidence. The uncinate processes were resected partially to correct the deformity maximally. Great care was taken to avoid injuries to the vertebral artery. We implanted a proper sized lordotic cage, in which filled with excised between-vertebral osteophytes. Finally, the cervical spine was fixed using a precontoured plate according to the normal cervical lordosis. In ACCF group, either one- or multi-segmental corpectomy was performed to decompress the anterior aspect of the dura. We properly distracted the intervertebral spaces across the corpectomy with a Caspar spreader. We partially removed the bilateral uncovertebral joints until complete release. We scraped to blush the bony endplates. We implanted either a titanium mesh cage with bone grafts or a long iliac crest graft, and fixed the cervical spine with a long lordotic plate. Post-operatively, the patients of both groups stayed in bed for 1 to 3 days, followed by rehabilitation under protection using a Philadelphia collar for 2 months.

2.3. Radiological assessments

Preoperatively, the patient routinely underwent MRI scans and X-ray tests (anteroposterior, lateral, and flexion/extension lateral views). The patient underwent routine X-rays or CT scans 3, 6, and 12 months after surgery, as well as at the final follow-up. We defined intervertebral fusion criteria as the presence of continuous bone connecting the endplates, absence of a radiolucent graft-host bony gap, and <3° measured motion between adjacent vertebral bodies on flexion-extension radiographs.

We measured cervical local kyphotic angle (LKA) between the tangents drawn at the posterior margins of the most cranial and the most caudal vertebra of the kyphotic curve using the Harrison posterior tangent method [14]. Cervical lordotic angles were negative in sign (-Rx), while the local kyphotic angles were positive in sign (+Rx). The largest + Rx was the angle of the local kyphotic curve (Fig. 1). A positive angle was defined as a kyphotic curve. The C2-7 Cobb angle was obtained by the perpendicular lines drawn along the C2 and C7 inferior endplates. The T1 slope was measured as the angle between a horizontal line and the superior endplate of T1 [15]. C2-7 SVA was defined as the distance between the posterosuperior endplate of C7 and the vertical line from the center of the C2 body [16] (Fig. 2). Cage subsidence was defined as reduction more than 2 mm in the midline disc height (MDH) at the postoperative follow-up compared to 1 week postoperatively [17].

The first and second authors measured the pre- and postoperative cervical alignments independently three times on the standing lateral X-ray (200% magnification), and the mean value was analyzed. The interobserver errors were <5%.

2.4. Clinical assessment

We assessed the patient's neurological function using the Japanese Orthopedic Association (JOA) cervical score [18]. We calculated neurological recovery rate using the Hirabayashi method: (Postoperative JOA - Preoperative JOA)/(17 – Preoperative JOA) × 100%. Neurological recovery rates were graded as following: excellent (≥75%), good (50% to 74%), fair (25% to 49%) and poor (<25%).

We quantified axial symptom (AS) severity using the Neck Disability Index (NDI, 0 = no disability, 50 = total disability) [19]. Based on the NDI ranking system, patients' scores were ranked as no disability (0–4), mild disability (5−14), moderate disability (15–24), severe disability (25–34), and complete disability (≥35).

Postoperative complications, including dysphagia, hoarseness, cerebrospinal fluid leakage, pseudarthrosis, iatrogenic spinal cord injury, vascular injury and wound problems, were recorded at any time.

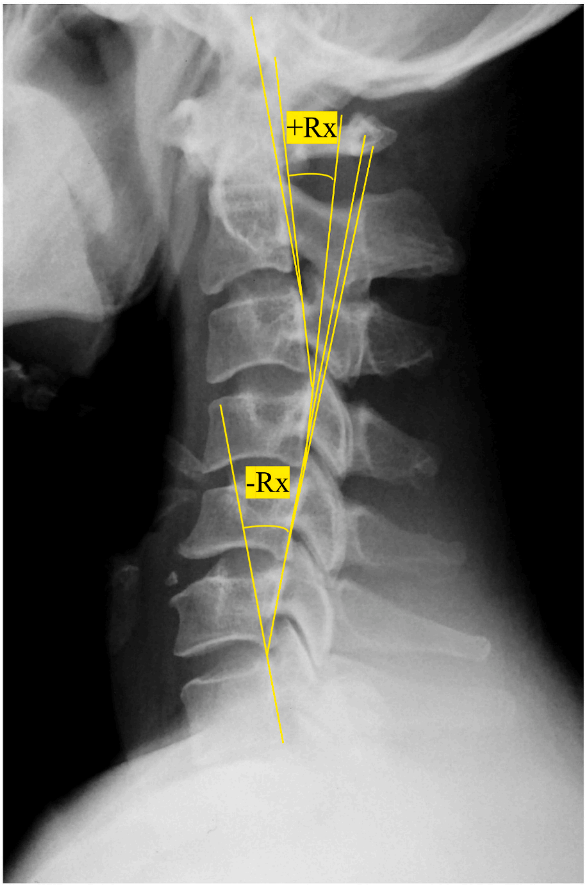

Fig. 1. The posterior tangents located on any kyphotic area in the cervical curve. Cervical lordotic angles are negative in sign (-Rx), while the kyphotic angles are positive in sign (+Rx). The largest + Rx is the angle of the local kyphotic curve.

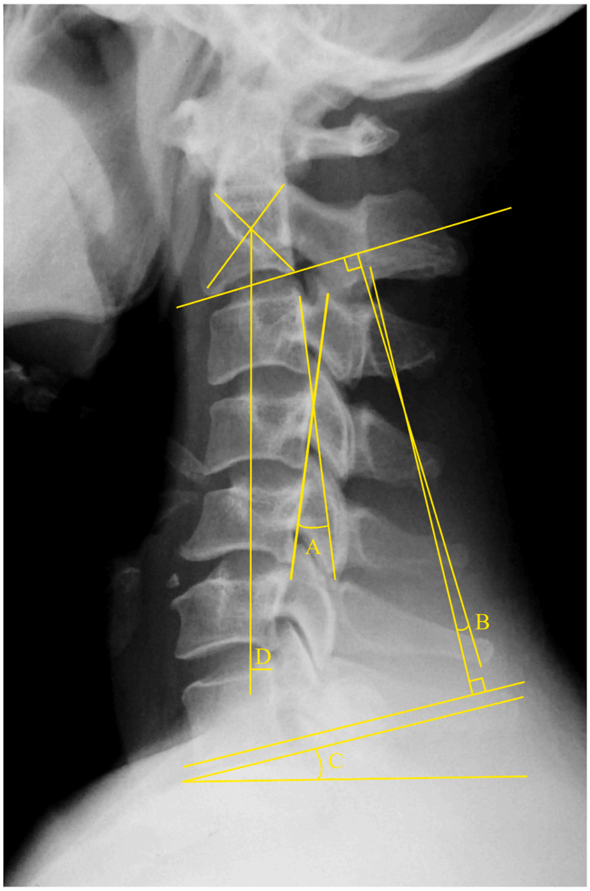

Fig. 2. Radiographic measurements. A: Cervical LKA was measured using the Harrison posterior tangent method. B: C2–7 Cobb angle. C: T1 slope. D: C2–7 SVA. SVA indicates sagittal vertical axis.

2.5. Statistical analysis

We analyzed the data using IBM SPSS Statistics, version 21.0. (IBM Corp., Armonk, NY, USA). Continuous variables were shown as means ± standard deviation. The qualitative data were analyzed using the Chi square test. A paired *t*-test was used to evaluate the statistical differences between pre and postoperative parameters. Statistical comparisons between ACDF group and ACCF group were performed regarding the LKA, LKA correction, C2-7 Cobb angle, T1 slope, C2-7 SVA, JOA score, recovery rate, NDI and NDI recovery using the independent sample *t*-test, regarding the neurological recovery rate grade using Pearson Chi-Square test, and regarding the NDI ranking system using Mann-Whitney *U* test. Pearson's correlation coefficient was used to examine the correlation between LKA correction and recovery rate, and between LKA correction and NDI recovery in each group. Between-group subsidence was compared using ANOVA and Student–Newman–Keuls test among the data obtained 6 months, 12 months after surgery, as well as at the final follow-up. A *P*-value of less than 0.05 was considered statistically significant.

3. Results

This retrospective study consisted of 104 patients (53 patients in ACDF group; 51 patients in ACCF group) (Table 1). The patients' age, gender, operating segments, presenting symptoms and follow-up time showed no significant differences ($P > 0.05$) between the ACDF and ACCF groups. However, statistically significant differences were demonstrated between the two groups regarding the operating time ($t = 10.16$, $P < 0.001$) and intraoperative blood loss ($t = 7.15$, $P < 0.001$).

3.1. Radiographic results

In ACDF group, statistically significant differences were shown between the pre- and postoperative parameters regarding the LKA ($t = 29.30$, $P < 0.001$), C2-7 Cobb angle ($t = 12.85$, $P < 0.001$), T1 slope ($t = 7.34$, $P < 0.001$), and C2-7 SVA ($t = 4.56$, $P < 0.001$) (Fig. 3A–D). In ACCF group, statistically significant differences were also shown between pre- and postoperative parameters regarding the LKA ($t = 34.28$, $P < 0.001$), C2-7 Cobb angle ($t = 17.58$, $P < 0.001$), T1 slope ($t = 5.26$, $P < 0.001$), and C2-7 SVA ($t = 2.33$, $P <$

Table 1
Patient characteristics.

Characteristics	ACDF group	ACCF group	Statistical	P
Total (n = 104)	(n = 53)	(n = 51)	Value	Value
Mean Age, year (range)[a]	61.09 ± 8.72 (46–75)	58.96 ± 8.42 (45–73)	1.27	0.207
Gender				
Male	35	31	0.31	0.578
Female	18	20		
Operating segments				
1 segment	11	3	4.98	0.083
2 segments	28	31		
3 segments	14	17		
Presenting symptoms				
Weakness				
Upper extremity	39	36	0.12	0.733
Lower extremity	24	22	0.05	0.826
Extremity numbness hyperesthesia	33	30	0.13	0.720
Gait instability	36	34	0.02	0.891
Hyperreflexia	41	38	0.12	0.734
Hoffman sign	38	37	0.01	0.923
Babinski sign	25	23	0.05	0.832
Clonus	12	13	0.12	0.734
Operating time (min)[a]	89.11 ± 16.81	120.98 ± 15.09	10.16	<0.001
Intraoperative blood loss (ml)[a]	91.00 ± 26.03	136.18 ± 37.58	7.15	<0.001
Complications [b]				
Dysphagia	15	19	129.00	0.005
Hoarseness	3	5		
Cerebrospinal fluid leak	0	1		
Pseudarthrosis	0	2		
Follow-up time, month (range)[a]	29.7 ± 5.4 (24–42)	30.8 ± 6.6 (24–42)	0.95	0.344

[a] *t*-test.
[b] Mann-Whitney *U* test.

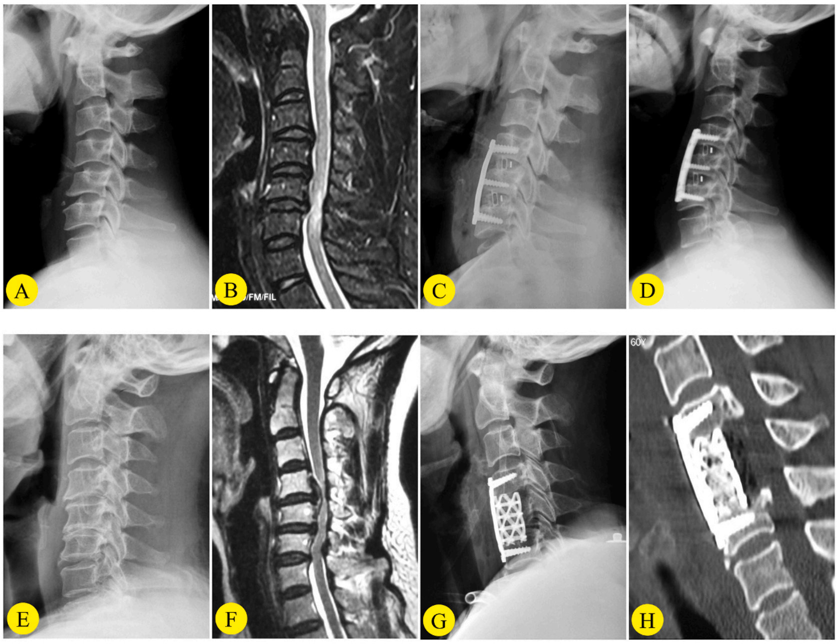

Fig. 3. A 53-year-old man who underwent ACDF. A: The preoperative lateral X-ray shows LKA, C2–7 cobb angle, T1slope, and C2-7 SVA were 16°, 10°, 14°, and 11 mm, respectively. B: Preoperative MRI showing C4-6 spinal cord compression combined with kyphosis. C: A postoperative lateral X-ray showing ACDF. D: On the lateral X-ray of 2.5 years after surgery, the LKA, C2–7 cobb angle, T1slope, and C2-7 SVA were −8°, 9°, 18°, and 21 mm, respectively. A 60-year-old woman who underwent ACCF. E: The preoperative lateral X-ray shows LKA, C2–7 cobb angle, T1slope, and C2-7 SVA were 19°, 11°, 15°, and 18 mm, respectively. F: Preoperative MRI showing C4-6 spinal cord compression combined with kyphosis. G: A postoperative lateral X-ray showing ACCF. H: On the CT image of 3 years after surgery, the LKA, C2–7 cobb angle, T1slope, and C2-7 SVA were −2°, 4°, 19°, and 27 mm, respectively.

0.001) (Fig. 3E–H). The preoperative LKA, C2-7 Cobb angle, T1 slope and C2-7 SVA showed no significant differences between the two groups ($P > 0.05$). However, statistically significant differences were demonstrated between the two groups regarding the postoperative LKA ($t = 3.46$, $P = 0.001$), LKA correction ($t = 8.19$, $P < 0.001$) (Fig. 4 A), C2-7 Cobb angle ($t = 3.41$, $P = 0.001$), T1 slope ($t = 2.77$, $P = 0.007$) and C2-7 SVA ($t = 2.58$, $P = 0.011$). (Table 2).

3.2. Functional outcomes

Statistically significant differences were shown between pre- and postoperative JOA scores in ACDF group ($t = 30.83$; $P < 0.001$) and in ACCF group ($t = 24.81$, $P < 0.001$), respectively. However, no significant differences were demonstrated between the two groups regarding pre- and postoperative JOA scores ($t = 0.18$, $P = 0.860$; $t = 0.99$, $P = 0.326$). (Table 3).

The recovery rates were 77.72% ± 10.87% after ACDF and 75.80% ± 15.27% after ACCF, respectively. The recovery rate showed no significant difference between the two groups ($t = 0.74$, $P = 0.462$). According to the neurological recovery rate grade, the neurological recovery was excellent in 34 (64.2%) patients and good in 19 (35.8%) patients in ACDF group. In ACCF group, the neurological recovery was excellent in 27 (52.9%) patients and good in 24 (47.1%). Based on the Pearson Chi-Square test, the neurological recovery rate grade showed no statistically significant differences between the two groups ($\chi^2 = 1.35$, $P = 0.246$). LKA correction showed positive correlations with the recovery rate ($r = 0.48$, $P < 0.001$) (Fig. 4 B).

3.3. Axial symptoms

Statistically significant differences were demonstrated between pre- and postoperative NDI in ACDF group ($t = 33.19$; $P < 0.001$) and in ACCF group ($t = 22.97$, $P < 0.001$), respectively. The postoperative NDI also showed a significant difference between the two groups ($t = 2.72$, $P = 0.008$). NDI recovery was 25.70 ± 6.18 after ACDF and 22.86 ± 7.22 after ACCF, respectively. NDI recovery showed a significant difference between the two groups ($t = 2.16$, $P = 0.034$). LKA correction showed the positive correlations with the NDI recovery in ACDF group ($r = 0.49$, $P < 0.001$), and in ACCF group ($r = 0.55$, $P < 0.001$) (Table 4; Fig. 4C).

According to the NDI ranking system, there was no disability in 16 patients and mild disability in 37 patients in ACDF group. In ACCF group, there were no disabilities in 11 patients, mild disability in 27 patients and moderate disability in 13 patients (Table 4). Based on the Mann-Whitney U test, the NDI ranking system showed a significant difference between the two groups ($U = 432$, $P < 0.001$).

3.4. Complications

In ACDF group, the patients suffered dysphagia (15/53; 28.3%) and hoarseness (3/53; 5.7%), respectively. In ACCF group, the patients suffered dysphagia (19/51; 37.3%), hoarseness (5/51; 9.8%), cerebrospinal fluid leak (1/51; 2.0%) and pseudarthrosis (2/51; 3.9%), respectively. Based on the Mann-Whitney U test, ACCF group carried higher incidences of complications than ACDF group ($U = 129$, $P = 0.005$) (Table 1). There were no major iatrogenic neurological or vascular injury, or wound infection in the two groups.

In ACDF group, there were significant differences ($F = 3.25$, $P = 0.041$) regarding cage subsidence between postoperative 6 months and the final follow-up, while no difference ($P > 0.05$) between postoperative 6 months and 12 months follow-up and between postoperative 12 months and the final follow-up. In ACCF group, there were significant differences ($F = 53.96$, $P < 0.001$) regarding cage subsidence among postoperative 6 months, 12 months and the final follow-up. There were statistically significant differences ($P < 0.05$) between the two groups at the postoperative 6 months, 12 months and the final follow-up (Table 5).

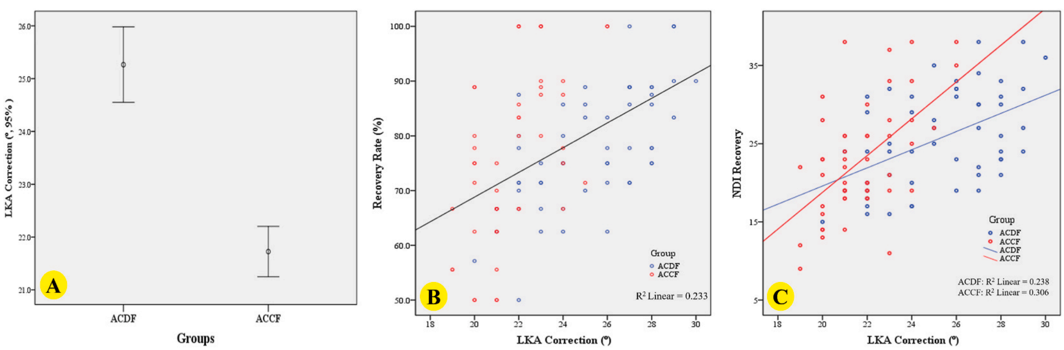

Fig. 4. A: LKA correction in each group. The difference between the two groups for LKA correction was statistically significant ($t = 8.19$, $P < 0.001$). B: Correlation between LKA correction and recovery rate ($r = 0.48$, $P < 0.001$). C: Correlation between LKA correction and NDI recovery (Axial symptom severity) in ACDF group ($r = 0.49$, $P < 0.001$), and in ACCF group ($r = 0.55$, $P < 0.001$).

Table 2
Pre- and postoperative final follow-up cervical radiological data in each group.

Parameter	ACDF group (n = 53)	ACCF group (n = 51)	*t* value[b]	P value
LKA[a] (°)				
Preoperative	15.60 ± 3.08	15.18 ± 2.93	0.73	0.470
Postoperative follow-up	−9.66±-5.47	−6.55±-3.45	3.46	0.001
t value[b]	29.30	34.28		
P value	<0.001	<0.001		
LKA correction (°)	25.26 ± 2.60	21.73 ± 1.70	8.19	<0.001
C2-7 Cobb angle				
Preoperative	16.75 ± 3.57	16.43 ± 3.67	0.46	0.650
Postoperative follow-up	7.49 ± 3.85	5.27 ± 2.65	3.41	0.001
t value[b]	12.85	17.58		
P value	<0.001	<0.001		
T1 slope (°)				
Preoperative	18.96 ± 5.24	18.61 ± 4.46	0.37	0.711
Postoperative follow-up	25.89 ± 4.45	23.39 ± 4.74	2.77	0.007
t value[b]	7.34	5.26		
P value	<0.001	<0.001		
C2-7 SVA				
Preoperative	16.58 ± 5.84	16.16 ± 5.66	0.38	0.705
Postoperative follow-up	22.13 ± 6.67	18.88 ± 6.17	2.58	0.011
t value[b]	4.56	2.33		
P value	<0.001	0.022		

[a] LKA: Local kyphotic angles.
[b] *t*-test.

Table 3
Pre- and postoperative final follow-up JOA score and neurological recovery rate in each group.

Parameter	ACDF group (n = 53)	ACCF group (n = 51)	Statistic value[a]	P value
JOA score [a]				
Preoperation	8.91 ± 1.23	8.86 ± 1.25	0.18	0.860
Postoperative follow-up	15.23 ± 0.85	15.02 ± 1.26	0.99	0.326
t value	30.83	24.81		
P value	<0.001	<0.001		
Recovery rate (%)[a]	77.72 ± 10.87	75.80 ± 15.27	0.74	0.462
Neurological recovery rate grade [b]				
Excellent (≥75%)	34	27	1.35	0.246
Good (50–74%)	19	24		
Fair (25–49%)	0	0		
Poor (<25%)	0	0		

[a] *t*-test.
[b] Pearson Chi-Square test.

Table 4
Pre- and postoperative final follow-up Axial symptom severity (NDI) in each group.

Axial symptoms	ACDF group (n = 53)	ACCF group (n = 51)	Statistic value[a]	P value
NDI [a]				
Preoperation	32.49 ± 4.27	32.20 ± 4.27	0.35	0.726
Postoperative follow-up	6.79 ± 3.68	9.33 ± 5.69	2.72	0.008
t value	33.19	22.97		
P value	<0.001	<0.001		
NDI recovery[a]	25.70 ± 6.18	22.86 ± 7.22	2.16	0.034
NDI ranking system [b]				
No disability (0–4)	16	11	432.00	<0.001
Mild disability (5-14)	37	27		
Moderate disability (15–24)	0	13		
Severe disability (25–34)	0	0		
Complete disability (≥35)	0	0		

[a] *t*-test.
[b] Mann-Whitney *U* test.

Table 5
Postoperative cage subsidence in each group.

Parameter	ACDF group (n = 53)	ACCF group (n = 51)	*t* value[a]	P value
6 months after surgery (mm)	0.53 ± 0.25	0.68 ± 0.28	2.98	0.004
12 months after surgery (mm)	0.61 ± 0.49	1.19 ± 0.59	5.48	<0.001
Final follow-up (mm)	0.77 ± 0.66	1.60 ± 0.43	7.58	<0.001
F value[b]	3.25	53.96		
P value	0.041	<0.001		

[a] *t*-test.
[b] ANOVO and Student–Newman–Keuls test.

4. Discussion

Currently, the optimal treatment of LKCSM through the different anterior approaches is still debated. We found that satisfactory neurological improvement can be achieved using either ACDF or ACCF for the LKCSM patients who have ≤3 segments of spinal cord compression. This study also confirmed that CLK correction caused significant improvement in neurological function and AS, as well as the increase in T1 slope and C2-7 SVA. However, ACDF was more favorable than ACCF in the CLK correction.

Cervical local kyphosis is often seen and potentially debilitating condition [3]. Nearly half a century, the anterior approach was widely applied for cervical degenerative disease due to radiculopathy and myelopathy [4]. The anterior approach can effectively decompress the spinal cord, remove anterior bony spurs and disc fragments, restore intervertebral height, and correct segmental kyphosis. Nevertheless, the anterior approach had a high incidence of complications, such as dysphagia, hoarseness, air-way obstruction, iatrogenic spinal cord injury, cerebrospinal fluid leakage, pseudarthrosis, and graft failure [6,7]. Therefore, regarding ≤3 segments of LKCSM, the optimal surgical strategy remains controversial for spinal surgeons.

Wu et al. [20] reported that CLK was associated with severe myelopathy symptoms, and the LKA threshold was probable to be 7°. CLK may increase the spinal intramedullary pressure, and hinder neurological recovery. Zhong et al. [21] reported that MRI T2-hyperintensity and congenital spinal stenosis may highly produce the rapid progressive CSM, and early decompression of the spinal cord was suggested and can achieve good neurological recovery postoperatively. Our study showed that both ACDF and ACCF can obtain satisfactory neurological improvement for ≤3 segments of the LKCSM, and LKA correction showed positive correlations with the recovery rate. However, ACDF can correct cervical kyphosis more effectively than ACCF. Due to the large decompressive range of the spinal cord, ACCF is suitable for LKCSM with calcification of the herniated disc or segmental OPLL, and then ACDF is more suitable for LKCSM involving intervertebral disc herniation or spinal stenosis. Therefore, we speculated that LKA correction and adequately intraoperative cord decompression may play vital roles in the early postoperative neurological recovery.

The incidence rate of axial symptoms (AS) can be as high as 29.9% after ACDF [22] and 46.7% after ACCF [23], respectively. The pathophysiology of neck pain is complicated, and most likely associated with disc degeneration, herniation, and the loss of cervical lordosis, as well as bio-mechanical abnormality of facet joints, muscles, and ligaments [24,25]. The loss of cervical lordosis and even cervical kyphosis may gradually develop due to the long-term bad lifestyle. It remains unclear how cervical kyphotic correction improves the AS through the anterior cervical approaches. Xu et al. [26] believed that postoperative alleviation of neck pain may be associated with the transient relief of facet joint pressure when the vertebral distraction was performed. The loss of cervical lordosis much more severely affected the neck extensors than the neck flexors in patients with neck pain. The present study illustrated that AS was improved by cervical kyphotic correction with a positive correlation, and ACDF was more favorable than ACCF. Thus, we speculated that CLK correction changed the bio-mechanical distribution of discs and facet joints, and decreased the stress of muscles and ligaments, further contributing to postoperative neck pain alleviation.

Recently, the T1 slope and C2-7 SVA represent the assessment of global sagittal balance, and each parameter is considered as a helpful radiographic index in predicting the presence of cervical kyphosis [27]. T1 slope has steady morphological value in an individual and significantly affects the balance of cervical sagittal alignment. Lee et al. [28] supported that the T1 slope can be used to predict the postoperative cervical kyphotic changes, and was also strongly associated with C2–C7 SVA. Wang et al. [29] demonstrated that decreased T1 slope postoperatively prevented the cervical spine to tilt forward by regulating C2-7 SVA, and facilitates the neurological recovery. In surgical planning and decision-making, the utilization of key radiological parameters can allow surgeons to optimize clinical outcomes for CSM [30]. In this study, we observed that after CLK was corrected, the C2-7 Cobb angle was restored, and the T1 slope and C2-7 SVA were increased. The increasing of T1 slope and C2-7 SVA can lead to a greater degree of lordotic curvature, and maintain the C2-7 lordosis forward gaze. In contrast, as the LKA continues to be corrected, the angle of cervical lordosis is increased, and then the C2-7 SVA moves backward. Lin et al. [27] reported that the patients with preoperative high T1 slope and large C2–C7 SVA carried a higher risk of postoperative cervical malalignment. For treating LKCSM, careful preoperative planning with special attention to radiographic parameters is mandatory as per the exhaustive assessment of global sagittal balance.

Transient dysphagia and hoarseness are the most frequent complications after anterior cervical approaches, with incidence rates ranging from 2.7% to 33.3% and from 3.0% to 11%, respectively [31,32]. Multifactors were reported by previous studies [33,34], including endocrine disorder, esophageal injury, the superior or recurrent laryngeal nerve injury, prevertebral or pharyngeal swelling, hematoma, thicker cervical plate implanting, and the surrounding scar formation. In our study, dysphagia and hoarseness were usually seen in patients with multisegmental spinal cord decompression, prolonged traction on the esophagus during surgery, and short wide necks. Nonetheless, administration of low doses of glucocorticoid and dehydrant for 3 to 5 days can significantly improve dysphagia and hoarseness. CSF leak is a serious complication of spinal surgery, and the incidence rate is up to 0.6% for patients who undergo the anterior cervical approaches [35]. Consistent with previous studies [36,37], our findings also demonstrated that the incidence rates of CSF leak and pseudarthrosis were significantly low in ACDF, compared to ACCF. After repair of the teared dura during surgery, CSF drainage was required within 3 to 5 days after surgery. No patient underwent secondary surgery due to the complication in the follow-up period.

Cage subsidence is caused by the sinking of the cage into the endplate of adjacent vertebral body. Severe cage subsidence can decrease the Cobb angle and intervertebral height, resulting in implant loosening or breakage [38]. The risk factors of cage subsidence are associated with patient age, bone mineral density, device type, surgical segment, bone graft, intraoperative over-distraction, cage material and geometry [17,38]. ACDF provides more rigid fixation points in correction of cervical kyphosis, while ACCF straightens the cervical spine and only provides two fixation points, resulting in increased stress between the remaining vertebral bodies. It may be one of the reasons that cage subsidence is more common in ACCF than ACDF. Consistent with the previous study [39], our results also confirmed that ACCF had a higher rate of cage subsidence than ACDF. Therefore, cage subsidence may be inevitable due to multiple factors. However, protection of bony endplate and rigid internal fixation can effectively prevent cage subsidence.

Adjacent disc disease (ADD) refers to new degenerative radiographic changes in the intervertebral discs adjacent to the previously fused segment(s), accompanied by related symptoms, such as radiculopathy, myelopathy, or coronal-sagittal instability. Jackson et al. [40] reported that nearly 25.6% of patients undergoing ACDF may develop symptomatic ADD and require reoperation within 10 years. CLK correction may change the intervertebral angle of the adjacent segments, leading to axial load shifting from the posterior column to the anterior column. The axial load shifting can increase the mechanical stress on the adjacent segments, which may interfere with the nutrition supply of intervertebral discs and accelerate the process of ADD [41]. Segmental kyphosis was considered a risk factor for ASD after ACDF [42]. However, the exact mechanisms underlying the progression of ADD remain not yet fully clear. The development of ADD is a multifactorial situation, including natural degeneration, segmental kyphosis, surgical technique and fusion [43]. The medium- and long-term study in this cohort is ongoing to investigate the occurrence and progression of ADD caused by cervical kyphotic correction.

The limitations of our study includes: (1) this study only included the patients with ≤3 segments of LKCSM, and only ACDF and ACCF were selected for the anterior approach; (2) all operations were performed by the same surgical team in a single hospital, which may produce the selection bias; (3) the patient size was relatively small; (4) our retrospective design has inherent weaknesses, which may produce a statistical bias; (5) the occurrence and progression of ADD caused by cervical kyphotic correction should be followed up for a longer time to ascertain the outcomes better; and (6) there is still a need for long-term, prospective, multi-center, large-scale clinical studies to clarify these results.

5. Conclusions

LKCSM with ≤3 segments of spinal cord compression can be improved with either ACDF or ACCF, resulting in satisfactory neurological outcomes. CLK correction can significantly improve the neurological function and AS, and increase the T1 slope and C2-7 SVA. However, ACDF was more favorable than ACCF in the CLK correction.

Declarations

Author contribution statement

Wei Du; Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Hai-Xu Wang, Jie Lv, Shuai Wang; Performed the experiments; Contributed reagents, materials, analysis tools or data. Yong Shen, Xu Zhang; Analyzed and interpreted the data.

Rong Chen, Li Zhang; Conceived and designed the experiments.

Data availability statement

Data included in article/supplementary material/referenced in article.

Funding statement

This study was funded by the Natural Science Foundation of Hebei Province (No. H2022206432) and Health Commission of Hebei Province (No. 20180407). No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Li Zhang reports financial support was provided by Natural Science Foundation of Hebei Province.

References

[1] W. Du, H.X. Wang, J.T. Zhang, F. Wang, X. Zhang, Y. Shen, et al., Cervical alignment and clinical outcome of anterior decompression with fusion vs. posterior decompression with fixation in kyphotic cervical spondylotic myelopathy, Front. Neurosci. 16 (2022), 1029327, https://doi.org/10.3389/fnins.2022.1029327.
[2] Y. Ogura, J.R. Dimar, M. Djurasovic, L.Y. Carreon, Etiology and treatment of cervical kyphosis: state of the art review-a narrative review, J. Spine Surg. 7 (3) (2021) 422–433, https://doi.org/10.21037/jss-21-54.
[3] A. Sivaganesan, H.J. Kim, A review of indications, surgical technique, and outcomes for the cervical pedicle subtraction osteotomy, J. Am. Acad. Orthop. Surg. 30 (3) (2022) e295–e300, https://doi.org/10.5435/JAAOS-D-21-00177.
[4] C.J. Chang, Y.F. Liu, Y.M. Hsiao, Y.H. Huang, K.C. Liu, R.M. Lin, et al., Comparison of anterior cervical discectomy and fusion versus artificial disc replacement for cervical spondylotic myelopathy: a meta-analysis, J. Neurosurg. Spine 22 (2022) 1–10, https://doi.org/10.3171/2022.2.SPINE211500.
[5] P.K. Louie, V.M. Nemani, J.A. Leveque, Anterior cervical corpectomy and fusion for degenerative cervical spondylotic myelopathy: case presentation with surgical technique demonstration and review of literature, Clin. Spine Surg. 35 (10) (2022) 440–446, https://doi.org/10.1097/BSD.0000000000001410.
[6] M. Lannon, E. Kachur, Degenerative cervical myelopathy: clinical presentation, assessment, and natural history, J. Clin. Med. 10 (16) (2021) 3626, https://doi.org/10.3390/jcm10163626.
[7] J.R. McCormick, A.J. Sama, N.C. Schiller, A.J. Butler, C.J. Donnally 3rd, Cervical spondylotic myelopathy: a guide to diagnosis and management, J. Am. Board Fam. Med. 33 (2) (2020) 303–313, https://doi.org/10.3122/jabfm.2020.02.190195.
[8] K.R. Kim, C.K. Lee, J.Y. Park, I.S. Kim, Preoperative parameters for predicting the loss of lordosis after cervical laminoplasty, Spine 45 (21) (2020) 1476–1484, https://doi.org/10.1097/BRS.0000000000003604.
[9] T. Abe, M. Miyazaki, T. Ishihara, S. Kanezaki, N. Notani, M. Kataoka, et al., Analysis of the risk factors for increasing cervical sagittal vertical axis after cervical laminoplasty for cervical spondylotic myelopathy, Arch. Orthop. Trauma Surg. 142 (4) (2022) 553–560, https://doi.org/10.1007/s00402-020-03667-1.
[10] K. Ninomiya, T. Shiraishi, R. Aoyama, S. Nori, J. Yamane, K. Kitamura, et al., Analysis of the impact of spinopelvic radiographic parameters on the severity of cervical spondylotic myelopathy, J. Orthop. Sci. 25 (6) (2020) 966–974, https://doi.org/10.1016/j.jos.2020.01.006.
[11] W. Du, S. Wang, H. Wang, J. Zhang, F. Wang, X. Zhang, et al., Cervical alignment and clinical outcome of open-door laminoplasty vs. laminectomy and instrumentation in kyphotic multilevel cervical degenerative myelopathy, Arch. Orthop. Trauma Surg. 143 (3) (2023) 1429–1440, https://doi.org/10.1007/s00402-021-04316-x.
[12] G.W. Smith, R.A. Robinson, The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion, J. Bone Joint Surg. Am. 40-A (3) (1958) 607–624.
[13] R.B. Cloward, The anterior approach for removal of ruptured cervical disks, J. Neurosurg. 15 (6) (1958) 602–617, https://doi.org/10.3171/jns.1958.15.6.0602.
[14] D.E. Harrison, D.D. Harrison, R. Cailliet, S.J. Troyanovich, T.J. Janik, B. Holland, Cobb method or Harrison posterior tangent method: which to choose for lateral cervical radiographic analysis, Spine 25 (16) (2000) 2072–2078, https://doi.org/10.1097/00007632-200008150-00011.
[15] T.H. Kim, S.Y. Lee, Y.C. Kim, M.S. Park, S.W. Kim, T1 slope as a predictor of kyphotic alignment change after laminoplasty in patients with cervical myelopathy, Spine 38 (16) (2013) E992–E997, https://doi.org/10.1097/BRS.0b013e3182972e1b.
[16] W.K. Kwon, P.S. Kim, S.Y. Ahn, J.Y. Song, J.H. Kim, Y.K. Park, et al., Analysis of associating factors with C2-7 sagittal vertical axis after two-level anterior cervical fusion: comparison between plate augmentation and stand-alone cages, Spine 42 (5) (2017) 318–325, https://doi.org/10.1097/BRS.0000000000001776.
[17] Z.Y. Jin, Y. Teng, H.Z. Wang, H.L. Yang, Y.J. Lu, M.F. Gan, Comparative analysis of cage subsidence in anterior cervical decompression and fusion: zero profile anchored spacer (ROI-C) vs. conventional cage and plate construct, Front Surg 8 (2021), 736680, https://doi.org/10.3389/fsurg.2021.736680.
[18] N. Nakano, T. Nakano, K. Nakano, Comparison of the results of laminectomy and open-door laminoplasty for cervical spondylotic myeloradiculopathy and ossification of the posterior longitudinal ligament, Spine 13 (7) (1988) 792–794, https://doi.org/10.1097/00007632-198807000-00014.
[19] H. Vernon, S. Mior, The Neck Disability Index: a study of reliability and validity, J. Manip. Physiol. Ther. 14 (7) (1991) 409–415.
[20] B. Wu, B. Liu, D. Sang, W. Cui, D. Wang, The association between cervical focal kyphosis and myelopathy severity in patients with cervical spondylotic myelopathy before surgery, Eur. Spine J. 30 (6) (2021) 1501–1508, https://doi.org/10.1007/s00586-021-06771-x.
[21] W. Zhong, L. Wang, T. Huang, X. Luo, Risk factors for rapid progressive neurological deterioration in patients with cervical spondylotic myelopathy, J. Orthop. Surg. Res. 16 (1) (2021) 75, https://doi.org/10.1186/s13018-021-02227-6.
[22] J. Zhou, L. Li, T. Li, Y. Xue, Preoperative Modic changes are related to axial symptoms after anterior cervical discectomy and fusion, J. Pain Res. 11 (2018) 2617–2623, https://doi.org/10.2147/JPR.S172953.
[23] Y. Zhang, H. Liu, H. Yang, B. Pi, Anterior cervical corpectomy and fusion versus discectomy and fusion for the treatment of two-level cervical spondylotic myelopathy: analysis of sagittal balance and axial symptoms, Int. Orthop. 42 (8) (2018) 1877–1882, https://doi.org/10.1007/s00264-018-3804-3.
[24] (a) M. Takahashi, K. Iwamoto, K. Tomita, T. Igawa, Y. Miyauchi, Incidence of cervical kyphosis and cervical posterior translation in neck pain associated with radiological evidence of degenerative disc disease, Musculoskelet. Sci. Pract. 62 (2022), 102637, https://doi.org/10.1016/j.msksp.2022.102637;
(b) M. Takahashi, K. Iwamoto, K. Tomita, T. Igawa, Y. Miyauchi, Incidence of cervical kyphosis and cervical posterior translation in neck pain associated with radiological evidence of degenerative disc disease, Musculoskelet. Sci. Pract. 62 (2022), 102637, https://doi.org/10.1016/j.msksp.2022.102637.
[25] M.J. Lambrechts, P.L. Brush, Y. Lee, T.Z. Issa, C.L. Lawall, A. Syal, et al., Patient reported outcomes following anterior and posterior surgical approaches for multilevel cervical myelopathy, Spine 48 (8) (2023) 526–533, https://doi.org/10.1097/BRS.0000000000004586.
[26] C. Xu, R. Wang, J. Li, H. Zhong, Z. Zhang, C. Cui, et al., Intervertebral-spreader-assisted anterior cervical discectomy and fusion prevents postoperative axial pain by alleviating facet joint pressure, J. Orthop. Surg. Res. 17 (1) (2022) 91, https://doi.org/10.1186/s13018-022-02983-z.
[27] B.J. Lin, K.T. Hong, C. Lin, T.T. Chung, C.T. Tang, D.Y. Hueng, et al., Impact of global spine balance and cervical regional alignment on determination of postoperative cervical alignment after laminoplasty, Medicine (Baltim.) 97 (45) (2018), e13111, https://doi.org/10.1097/MD.0000000000013111.
[28] J.S. Lee, D.W. Son, S.H. Lee, D.H. Kim, S.W. Lee, G.S. Song, The predictable factors of the postoperative kyphotic change of sagittal alignment of the cervical spine after the laminoplasty, J. Kor. Neurosurg. Soc. 60 (5) (2017) 577–583, https://doi.org/10.3340/jkns.2017.0505.007.
[29] D.F. Wang, X.Y. Li, C. Kong, C.X. Liu, B. Shi, S.B. Lu, Changes in T1 slope and cervical sagittal vertical axis correlate to improved neurological function recovery after cervical laminoplasty, Front Surg 9 (2022), 1002848, https://doi.org/10.3389/fsurg.2022.1002848.
[30] W.H. Waddell, W.E. Vaughan, A.M. Abtahi, Radiographic parameters in cervical myelopathy: review of current literature, Clin. Spine Surg. 35 (10) (2022) 389–395, https://doi.org/10.1097/BSD.0000000000001412.
[31] N. Nagoshi, L. Tetreault, H. Nakashima, P.M. Arnold, G. Barbagallo, B. Kopjar, et al., Risk factors for and clinical outcomes of dysphagia after anterior cervical surgery for degenerative cervical myelopathy: results from the AOSpine International and North America Studies, J. Bone Joint Surg. Am. 99 (13) (2017) 1069–1077, https://doi.org/10.2106/JBJS.16.00325.
[32] J. Bakhsheshian, V.A. Mehta, J.C. Liu, Current diagnosis and management of cervical spondylotic myelopathy, Global Spine J. 7 (6) (2017) 572–586, https://doi.org/10.1177/2192568217699208.
[33] Y. Shen, W. Du, L.F. Wang, Z. Dong, F. Wang, Comparison of Zero-profile device versus plate-and-cage implant in the treatment of symptomatic adjacent segment disease after anterior cervical discectomy and fusion: a minimum 2-year follow-up study, World Neurosurg. 115 (2018) e226–e232, https://doi.org/10.1016/j.wneu.2018.04.019.
[34] L. Tetreault, S.F. Lange, S. Chotai, M. Lupo, M.T. Kryshtalskyj, J.R. Wilson, et al., A systematic review of definitions for dysphagia and dysphonia in patients treated surgically for degenerative cervical myelopathy, Global Spine J. 12 (7) (2022) 1535–1545, https://doi.org/10.1177/21925682211035714.
[35] R. Harel, M. Nulman, G. Kimchi, N. Knoller, Short-term post-operative complications in 207 patients with multi-level degenerative cervical myelopathy: the effect of surgical approach, Neurol. Neurochir. Pol. 56 (5) (2022) 404–409, https://doi.org/10.5603/PJNNS.a2022.0052.
[36] Z. Yu, X. Shi, J. Yin, X. Jiang, N. Xu, Comparison of complications between anterior cervical diskectomy and fusion versus anterior cervical corpectomy and fusion in two- and three-level cervical spondylotic myelopathy: a meta-analysis, J. Neurol. Surg. Cent. Eur. Neurosurg. 84 (4) (2023) 343–354, https://doi.org/10.1055/s-0042-1747926.

[37] T. Wang, J. Guo, Y. Long, Z. Hou, Comparison of two anterior reconstructive techniques in the treatment of 3-level and 4 level cervical spondylotic myelopathy: a meta-analysis of last decade, Geriatr. Orthop. Surg. Rehabil. 13 (2022), 21514593221124415, https://doi.org/10.1177/21514593221124415.
[38] U.K. Dhar, E.L. Menzer, M. Lin, V. Hagerty, T. O'Connor, C.T. Tsai, et al., Factors influencing cage subsidence in anterior cervical corpectomy and discectomy: a systematic review, Eur. Spine J. 32 (3) (2023) 957–968, https://doi.org/10.1007/s00586-023-07530-w.
[39] T. Wang, H. Wang, S. Liu, H.D. An, H. Liu, W.Y. Ding, Anterior cervical discectomy and fusion versus anterior cervical corpectomy and fusion in multilevel cervical spondylotic myelopathy: a meta-analysis, Medicine (Baltim.) 95 (49) (2016), e5437, https://doi.org/10.1097/MD.0000000000005437.
[40] R.J. Jackson, R.J. Davis, G.A. Hoffman, H.W. Bae, M.S. Hisey, K.D. Kim, et al., Subsequent surgery rates after cervical total disc replacement using a Mobi-C Cervical Disc Prosthesis versus anterior cervical discectomy and fusion: a prospective randomized clinical trial with 5-year follow-up, J. Neurosurg. Spine 24 (5) (2016) 734–745, https://doi.org/10.3171/2015.8.SPINE15219.
[41] X. Wang, Y. Meng, H. Liu, H. Chen, B. Wang, Y. Hong, Cervical sagittal alignment after Prestige LP cervical disc replacement: radiological results and clinical impacts from a single-center experience, BMC Muscoskel. Disord. 22 (1) (2021) 82, https://doi.org/10.1186/s12891-021-03962-x.
[42] W. Xiong, J. Zhou, C. Sun, Z. Chen, X. Guo, X. Huo, et al., 5- to 1-fold intervertebral distraction is a protective factor for adjacent segment degeneration in single-level anterior cervical discectomy and fusion, Spine 45 (2) (2020) 96–102, https://doi.org/10.1097/BRS.0000000000003209, 0.
[43] V.N.E. Schuermans, A.Y.J.M. Smeets, N.P.M.H. Wijsen, I. Curfs, T.F.M. Boselie, H. van Santbrink, Clinical adjacent segment pathology after anterior cervical discectomy, with and without fusion, for cervical degenerative disc disease: a single center retrospective cohort study with long-term follow-up, Brain Spine 2 (2022), 100869, https://doi.org/10.1016/j.bas.2022.100869.