Comparison of flexion relaxation phenomenon after single-level and multi-level Anterior Cervical Discectomy and Fusion

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Abstract

Background This study aims to assess the influence of the number of fused segments on cervical paravertebral muscles by analyzing the changes of the cervical flexion relaxation phenomenon (FRP) after single-level and multi-level anterior cervical discectomy and fusion (ACDF).

Methods A total of 28 patients underwent ACDF were included, including 9 cases of 1-level, 12 of 2-level and 7 of 3 or 4-level. The flexion relaxation experiment of cervical erector spinae (CES) muscles was carried out at preoperative 3 days, postoperative 6 months and 12 months by surface electromyography (SEMG). Patients were examined by the neck Visual Analogue Scale (VAS), the cervical Japanese Orthopaedic Association (JOA) score and Neck Disability Index (NDI). C2-7 range of motion (ROM) at flexion and extension was evaluated by X-ray.

Results The FRP of all patients with 1-level ACDF was normalized (100%). Only 2/12 patients with 2-level ACDF had normalized FRP at the last follow-up, with increased flexion relaxation ratio (FRR) and decreased normalized SEMG activity than those before surgery. However, all patients with 3 or 4-level had decreased postoperative FRR and increased normalized SEMG activity in each phase. A significant correlation was found between the changes of C2-7 ROM and FRR in three groups.

Conclusions 1-level ACDF could normalize the FRP of cervical paravertebral muscles, which was not ideally recovered in patients with 2-level ACDF. However, 3 or 4-level ACDF could aggravate the SEMG activity and worsen the function of cervical paravertebral muscles. Our research strongly supported the passive structures hypothesis.

Background

Anterior Cervical Discectomy and Fusion (ACDF) is a safe and common therapeutic strategy cervical spondylosis [1–3]. Owing to the multiple advantages like reconstruction of the physiological curvature of the cervical spine, maintenance of cervical stability, decompression of the spinal cord, and less invasiveness to the posterior structures of the cervical spine, ACDF is generally considered to be superior than that of the posterior surgery [4, 5]. However, anterior cervical fusion with bone graft is reported to cause the loss of the cervical ROM, which may negatively influence cervical paravertebral muscles [6, 7].

Radiological changes of cervical paravertebral muscles after ACDF have been reported [7], while electrophysiological changes have been rarely analyzed. The flexion relaxation phenomenon (FRP), which was first proposed by Floyd and Silver, is defined as the decline or sudden silence of electromyographic activity of lumbar erector spinae muscle (LES) during full trunk flexion [8]. Three mechanisms are mainly responsible for FRP: (1) Transfer the extension moment from the active muscles to passive viscoelastic structures of the spine like the ligaments, capsules and vertebral discs [9, 10]; (2) Transfer the extension moment from the superficial paraspinal muscles to the deep paraspinal muscles [11, 12]; (3) Reflexive mechanisms involving tension mechanoreceptors in ligaments and other viscoelastic structures trigger the FRP [13]. In 1993, Meyer et al. [14] found the presence of FRP in cervical erector spinae (CES)

muscles. At present, FRP is often used to objectively measure the clinical improvement, providing very useful and objective information for the muscle function [15, 16].

This study aims to compare the changes of the FRP of CES after single-level and multi-level ACDF in patients with cervical spondylosis. Moreover, the potential correlation between the FRP and the clinical and radiological findings of patients with cervical spondylosis was identified.

Methods

Subjects

This study was approved by the Ethics Committee of our hospital, and conformed to the STROCSS (Strengthening the Reporting of Cohort Studies in Surgery) criteria [17]. We conducted a preoperative and postoperative study of 28 patients with cervical spondylosis receiving 1-4 level ACDF in a single institution from July 2019 to November 2021. Inclusion criteria: (1) Diagnosis of cervical spondylosis at C3-T1 by CT and MRI before operation; (2) Clinical symptoms and signs of spinal cord and nerve compression; (3) Ineffective or recurrent after 3 months of non-operative treatment; (4) Complications after successful ACDF were not reported. Exclusion criteria: (1) Subjects with cervical deformity, cervical trauma, cervical infection, cervical tumor, cervical tuberculosis or metabolic bone disease; (2) Previous brain and cervical surgery; (3) Severe cardiovascular disease or liver and kidney dysfunction; (4) Severe neurosis or mental illnesses; (5) Pregnancy. After obtaining the informed consent, every subject received a preliminary evaluation and flexion relaxation experiment before ACDF. All operations were performed by a spine surgeon. The postoperative evaluation and flexion relaxation experiment were performed at 6 months and 12 months postoperatively.

Surgical Procedures

After the induction of general endotracheal anesthesia, the patient was placed in a supine position on an operating table. ACDF was performed by the Smith-Robinson approach. A laminar spreader was placed in the disk space to fully expose the surgical field. Then, the surgeon removed the intervertebral disc and hyperplastic osteophytes adequately, and a cage filled with autologous or allogeneic bones was implanted. The laminar spreader was finally removed. The remaining diseased segments were similarly operated. A pre-bent plate with a suitable length was selected and fixed in front of the vertebral bodies. Each vertebral body was fixed with 2 cortical screws. After the C-arm fluoroscopy was ideal, the wound was washed, and sutured layer by layer. After resuscitation, the patient wearing a cervical collar returned to the ward (Figure 1).

Electromyography

A dual-channel surface electromyography (EMG) equipment (Jiangxi Nuocheng Electric Appliance Co. Ltd., China) was used to collect the original surface electromyography signals of CES on both sides of the neck. Bipolar disposal electrodes for EMG (Ag–AgCl) were applied bilaterally to the skin 2 cm away from

the central line of C4 spinous process, thus recording the activity of CES in the neck [18, 19]. A reference electrode was affixed to the right wrist to eliminate the interference of ECG signals and machine signals. The electrode was placed alongside the direction of muscle fibers, and skin impedance was reduced by removing hair and scrubbing skin with alcohol-soaked cotton swabs. The SEMG data were digitally filtered using a 20-480 Hz band-pass and sampled at 1000 Hz [common mode rejection ratio >110 dB, overall gain 1,000, noise < 1 μ V root mean square (RMS)].

Experimental Protocol

Every patient was asked to complete the neck Visual Analogue Scale (VAS), the cervical Japanese Orthopaedic Association (JOA) score and Neck Disability Index (NDI) questionnaire 3 days preoperatively, and 6 months and 12 months postoperatively to evaluate the clinical improvement. During the preoperative and postoperative examination, the Cobb angle between the inferior endplate of C2 vertebral body and C7 vertebral body at flexion and extension was measured by X-ray. Lordosis and kyphosis were expressed as a positive and negative value, respectively. C2-7 ROM was determined as the difference between lordotic angle and kyphotic angle during the extension and flexion of the cervical spine.

The patient was tested for 60 minutes in the laboratory 3 days preoperatively, and 6 months and 12 months postoperatively. During the test, the patient sat on an adjustable stool with the flexion of hips and knees at 90°. He or she was asked to position the feet, open the shoulders with both arms put on each side, and watched a point horizontal to the eyes [20]. At such a position, the patient was asked to maintain the starting position for 4 s (phase 1), the complete flexion for 4 s (phase 2), the sustained flexion for 4 s (phase 3), and extend and return to the starting position for 4 s (phase 4) [15, 20]. The speed was controlled by a digital metronome [10]. The experiment was repeated in triplicate. In order to normalize SEMG data, each subject underwent maximum voluntary isometric contractions (MVICs) of CES at the end of the trial, and electromyographic activities were recorded. The MVIC of CES was obtained in a sitting position, and the cuff connecting to a stable attachment at the same height was wrapped around the head. The patient was asked to pull the wire backward as much as possible. MVIC was recorded for three times (3×5 s) with an interval of 2 min to prevent muscle fatigue [15].

Data Analysis

The SEMG signals were filtered, and root mean square (RMS) values were obtained. The flexion relaxation ratio (FRR) has been widely used to quantify the relaxation ability of CES. FRR was defined as the ratio of the maximum SEMG value of the extension phase (phase 4) to the average SEMG value of the sustained flexion phase (phase 3) [15, 21]. According to the threshold value of 2.50, the value lower than 2.50 indicated the disappearance of FRP, and on the contrary, it indicated the existence of FRP [21, 22]. The RMS values of each phase and MVICs were normalized to obtain the SEMG activity intensity. The original SEMG values at different phases by the peak value of SEMG obtained during MVICs achieving in the tested muscle was defined as the process of SEMG normalization [23], which was helpful to increase the comparability between individuals.

Statistical Analysis

All statistical analyses were performed using SPSS version 29 (IBM Corp., Armonk, New York, USA). Data were expressed as mean $\pm$ standard deviations or percentages. Differences in the neck VAS, JOA, NDI, C2-7 ROM, FRR and the normalized EMG RMS values among three or more groups were compared by the analysis of variance. Non-normally distributed data were compared by the Kruskal-Wallis H test. Differences in the sex ratio, smoking rate, prevalence of diabetes and the proportion of postoperative FRP among the groups were compared by the Fisher's exact test. $P < 0.05$ was considered as statistically significant.

Results

A total of 28 patients with cervical spondylosis underwent the flexion relaxation test at 3 days before ACDF, and 6 months and 12 months after ACDF, involving 9 cases of 1-level, 12 of 2-level and 7 of 3 or 4-level. Their demographic data were shown in Table 1. No significant differences in the gender, age, BMI, smoking rate and prevalence of diabetes were detected among three subgroups ($P > 0.05$). None of patients in the three groups received cervical surgery again after ACDF, and cervical complications, including dyspnea, dysphagia, cage migration and screw back-out were not reported during the follow-up period.

Table 1
Patients Characteristics

	1 Level	2 Levels	3-4 Levels	p value
Overall	9	12	7	
Age (years)	53.0 $\pm$ 5.39	54.25 $\pm$ 5.36	55.14 $\pm$ 5.67	0.732
Sex(male/female)	4/5	7/5	3/4	0.746
Height (m)	1.65 $\pm$ 0.06	1.62 $\pm$ 0.06	1.65 $\pm$ 0.05	0.433
Weight (kg)	60.42 $\pm$ 4.37	57.10 $\pm$ 5.64	59.91 $\pm$ 4.75	0.288
BMI (kg/m ²)	22.13 $\pm$ 1.97	21.71 $\pm$ 2.50	22.08 $\pm$ 1.92	0.892
Smoking (%)	22.22%	25.00%	28.57%	0.959
Diabetes (%)	22.22%	16.67%	14.29%	0.819
BMI: body mass index				

Clinical and Radiological outcomes

As shown in Table 2, there was no significant difference in the neck VAS among the three groups before operation ($P > 0.05$). Although the neck VAS decreased significantly after ACDF in all three groups, no significant difference was detected ($P > 0.05$). There were no significant differences in the cervical JOA, NDI and C2-7 ROM among the three groups before operation ($P > 0.05$). At the last follow-up, the cervical JOA scores of the three groups significantly increased, showing a significant difference among the three

groups ($P<0.05$). NDI of the three groups significantly decreased after ACDF with a significant difference among three groups ($P<0.05$). Patients who underwent 1-level ACDF maintained a better C2-7 ROM than that of patients receiving 2-4 level ACDF at the last follow-up ($P<0.05$).

Table 2
Comparison of clinical and radiological outcomes according to surgical levels

Variable	1 Level	2 Levels	3-4 Levels	F	P-value
Neck VAS					
Pre 3 days	5.44 ± 0.88	5.92± 1.08	6.43 ± 0.98	1.924	0.167
Post 6 months	2.00± 1.00	2.33 ± 1.23	3.14 ± 0.69	2.422	0.109
Post 12 months	0.78 ± 0.67	1.08 ± 0.90	1.57 ± 0.98	1.713	0.201
Cervical JOA					
Pre 3 days	8.44±1.42	7.00±1.65	6.71±1.70	2.951	0.071
Post 6 months	12.11±1.27	11.33±1.61	11.00±2.00	1.038	0.369
Post 12 months	15.56±1.13	13.75±1.76	12.71±1.38	7.593	0.003*
NDI					
Pre 3 days	20.56 ± 2.07	22.17 ± 2.69	22.71 ± 2.69	1.700	0.203
Post 6 months	10.67±2.29	13.42 ±1.73	15.00±2.52	8.739	0.001*
Post 12 months	7.56 ± 2.01	11.08± 1.88	13.00± 2.16	15.851	<0.001*
C2-7ROM (°)					
Pre 3 days	48.78±12.77	45.02 ± 10.94	43.51 ± 11.35	0.456	0.639
Post 6 months	41.83 ± 12.11	37.52 ± 11.48	27.19 ± 9.93	3.403	0.049*
Post 12 months	46.30 ± 12.98	38.97 ± 11.52	26.24 ± 9.20	6.028	0.007*
Neck VAS, neck visual analogue scale; Cervical JOA, cervical Japanese Orthopaedic Association (JOA) score; NDI, Neck Disability Index					
*Statistically significant ($P<0.05$)					

Electromyography

FRR

The preoperative flexion relaxation phenomenon ($FRR<2.50$) disappeared and there was no significant difference in the FRR among the three groups ($F=1.594$, $P=0.223$). After ACDF, the FRP recovered in all patients with 1-level ACDF at 6 months (100%) and 12 months postoperatively (100%). A significant difference was detected between preoperative and postoperative FRR in patients with 1-level ACDF

($F=75.371$, $P<0.001$). One patient with 2-level ACDF had recovered FRP at 6 months (8.33%) and 2 recovered at 12 months (16.67%). The FRR was higher than that before operation in all patients with 2-level ACDF ($F=5.378$, $P=0.010$). However, FRP was not recovered in all patients with 3 or 4-level ACDF at 6 months and 12 months postoperatively (recovery rate 0%), which was significantly reduced compared with that before surgery ($F=8.028$, $P=0.003$) (Table 3, Figure 2, Figure 3).

Table 3
Comparison of preoperative and postoperative FRR

	1 Level	2 Levels	3-4 Levels	F	P-value
FRR					
Pre 3 days	1.943±0.214	1.799±0.257	1.737±0.251	1.594	0.223
Post 6 months	3.730±0.464	2.044±0.269	1.410±0.128	115.916	<0.001*
Post 12 months	3.910±0.403	2.147±0.274	1.398±0.130	156.675	<0.001*
F	75.371	5.378	8.028		
P-value	<0.001*	0.010*	0.003*		
FRR, flexion relaxation ratio					
*Statistically significant ($P<0.05$)					

Normalized SEMG activity

According to preoperative and postoperative analysis of the normalized SEMG RMS values in each phase in Table 4, Figure 2 and Figure 4, it is found that the normalized SEMG RMS values after 1-level and 2-level ACDF significantly decreased compared with those before surgery in the starting phase (1-level, $F=173.553$, $P<0.001$; 2-level, $F=14.812$, $P<0.001$), the complete flexion phase (1-level, $F=53.899$, $P<0.001$; 2-level, $F=9.423$, $P<0.001$), the sustained flexion phase (1-level, $F=230.274$, $P<0.001$; 2-level, $F=35.275$, $P<0.001$) and the extension phase (1-level, $F=20.403$, $P<0.001$; 2-level, $F=3.496$, $P=0.042$). Although the clinical symptoms of 3 or 4-level ACDF were improved after surgery, the normalized SEMG RMS values significantly increased in the starting phase ($F=618.031$, $P<0.001$), the complete flexion phase ($F=266.378$, $P<0.001$), the sustained flexion phase ($F=265.305$, $P<0.001$) and the extension phase ($F=80.785$, $P<0.001$). At the last follow-up, we found significant differences in the normalized SEMG RMS values between the three groups (phase 1, $F=2018.037$, $P<0.001$; phase 2, $F=687.328$, $P<0.001$; phase 3, $F=1116.202$, $P<0.001$; phase 4, $F=285.273$, $P<0.001$).

Table 4
Comparison of the normalized EMG activity in different phases of movement

	1 Level	2 Levels	3-4 Levels	F	P-value
phase 1					
Pre 3 days	0.052±0.005	0.062±0.003	0.066±0.004	29.591	<0.001*
Post 6 months	0.024±0.003	0.058±0.004	0.128±0.004	1470.455	<0.001*
Post 12 months	0.022±0.003	0.054±0.003	0.132±0.004	2018.037	<0.001*
F	173.553	14.812	618.031		
P-value	<0.001*	<0.001*	<0.001*		
phase 2					
Pre 3 days	0.095±0.004	0.104±0.005	0.110±0.006	19.411	<0.001*
Post 6 months	0.082±0.004	0.098±0.005	0.175±0.006	746.599	<0.001*
Post 12 months	0.075±0.005	0.095±0.006	0.177±0.007	687.328	<0.001*
F	53.899	9.423	266.378		
P-value	<0.001*	<0.001*	<0.001*		
phase 3					
Pre 3 days	0.065±0.003	0.073±0.005	0.077±0.006	13.673	<0.001*
Post 6 months	0.030±0.005	0.061±0.005	0.137±0.006	914.648	<0.001*
Post 12 months	0.027±0.004	0.057±0.005	0.140±0.006	1116.202	<0.001*
F	230.274	35.275	265.305		
P-value	<0.001*	<0.001*	<0.001*		
phase 4					
Pre 3 days	0.127±0.008	0.130±0.010	0.133±0.010	0.887	0.424
Post 6 months	0.112±0.006	0.124±0.007	0.193±0.010	262.950	<0.001*
Post 12 months	0.106±0.007	0.122±0.006	0.195±0.011	285.273	<0.001*
F	20.403	3.496	80.785		
P-value	<0.001*	0.042*	<0.001*		
phase 1: the starting phase; phase 2, the complete flexion phase; phase 3, the sustained flexion phase; phase 4, the extension phase					
*Statistically significant (P<0.05)					

We did not identify a significant correlation between the change of clinical outcomes (the neck VAS, the cervical JOA, NDI) and the FRR at 12 months postoperatively ($P > 0.05$). However, C2-7 ROM changes were significantly correlated with FRR in patients receiving 1-level, 2-level and 3 or 4-level ACDF at 12 months postoperatively ($R = -0.134$, $P < 0.05$; $R = -0.087$, $P = 0.049$; $R = 0.941$, $P < 0.05$) (Table 5 Table 5, Figure 5).

Table 5
The association between changes of FRP and the patient's clinical and radiological outcomes postoperative 12 months

Variable		Δ neck VAS	Δ cervical JOA	Δ NDI	Δ C2-7ROM
Δ FRR					
1 Level	r	-0.084	-0.094	-0.140	-0.134
	P-value	0.204	0.070	0.429	<0.05*
2 Levels	r	0.475	-0.059	-0.030	-0.087
	P-value	0.087	0.180	0.052	0.049*
3-4 levels	r	-0.195	0.029	0.124	0.941
	P-value	0.748	0.101	0.113	<0.05*
*Statistically significant ($P < 0.05$)					

Discussion

This study aims to investigate the effects of single-level and multi-level ACDF on the cervical paravertebral muscles. A simple flexion relaxation test was performed to evaluate the cervical erector muscle function after 1-level, 2-level and 3 or 4-level ACDF, and its correlation with clinical and radiological outcomes. By comparing the results 3 days before ACDF, and 6 months and 12 months after ACDF, the presence of FRP of CES and significantly improved function of the cervical paravertebral muscles at 1-level ACDF were detected. FRP of CES occurred in some patients with 2-level ACDF and the normalized SEMG activity showed an overall downward trend, but the improvement of the cervical paravertebral muscle function was not ideal compared with 1-level ACDF. Interestingly, clinical symptoms of the patients with 3 or 4-level ACDF were relieved effectively. However, CES did not effectively relax with even aggravated myoelectric activity due to the long-segment fixation, leading to a higher load on cervical paravertebral muscles and increased incidence of fatigue. In addition, our results showed a significant correlation between the changes of the FRR values and C2-7 ROM.

Clinical outcomes

We did not compare extensive clinical and radiological results with other studies because of the small sample size. In the postoperative follow-up, the neck VAS, the cervical JOA scores and NDI were significantly improved by single-level and multi-level ACDF. At the last follow-up, there was no difference in the neck VAS among the three groups, although cervical JOA scores and NDI were significantly different among the three groups, which were generally consistent with the previous report [24].

Radiological Outcomes

In this study, C2-7 ROM significantly decreased and the overall ROM of cervical spine decreased in the three groups at 6 months after ACDF. The cervical mobility of patients with 1-level and 2-level ACDF was partially recovered at 12 months postoperatively. The complete adjacent segments physiologically compensated for the motion loss of the fusion segment, thereafter maintaining the cervical movement in daily activities. However, this phenomenon was not observed at 12 months of 3 or 4-level ACDF, because more fused segments resulted in less compensatory movement [25].

Electromyography

The cervical FRP refers to a normal phenomenon in which the myoelectric activity on the surface of CES completely disappears when the cervical vertebra is completely flexible [14]. The indexes obtained from the conversion of the original SEMG values by different methods can be used to evaluate the relaxation and coordination ability of muscles [26, 16]. Generally, the flexion relaxation ratio (FRR), and the normalized SEMG RMS values in different phases are widely used to assess spinal diseases like cervical spondylosis and neck pain [15]. A previous study showed that in the flexion and extension of the cervical spine, three systems interact with each other to maintain the mobility stability of the spine, including the passive active tissue system composed of vertebral body, intervertebral disc, ligament and fascia, the active system of active contraction of the deep and superficial muscles of the cervical spine, and the control system dominated by the central nervous system. They complement each other, and the damage of any system would decrease of the stability of the cervical vertebra [27]. Previous studies have shown that the increased spinal motion instability leads to the change of motion control mode [28, 10]. Patients with cervical spondylosis have long-term instability of cervical motion due to intervertebral disc herniation and intervertebral joint degeneration, further leading to insufficient motion control of intervertebral joints, enlarged neutral zone and repeated microtrauma. Finally, a vicious circle forms to cause the neck pain. Pain in turn leads to increased sensitivity of motoneurons, which eventually cause paravertebral muscle contraction and enhanced EMG activity. As a result, more muscle fibers are recruited that allows additional extension moment to compensate for the stability of the passive system during movement, forming a protective mechanism [29–31]. In our study, flexion relaxation disappeared in all patients with preoperative cervical spondylosis, which was consistent with the previous findings.

ACDF is usually applied to the treatment of cervical degenerative diseases. The increase of fusion segments might increase the complexity of surgery, and the incidence of adverse events and reoperation [32, 33]. The present study focused on the functional changes of cervical paravertebral muscles after single-level and multi-level ACDF. A previous study reported that patients receiving percutaneous

endoscopic lumbar discectomy return to normal flexion relaxation postoperatively without destroying paravertebral muscles, and the disc compression is successfully relieved [34]. Without invading cervical paravertebral muscles, internal fixation devices at varying lengths are added to destroy the passive system during the procedure of ACDF, which might explain the differences in postoperative FRR and normalized EMG values in each phase. In this study, FRR and the normalized EMG RMS values of each phase were significantly improved after 1-level ACDF, resulting in the good relaxation of the cervical paravertebral muscles in the process of flexion and extension. Previous studies have shown that the spinal ligaments and the intervertebral discs are rich in mechanical receptors and nociceptors that receive signals from joint load, movement and inflammation [35, 36]. By minimizing the damage to the passive structures, 1-level ACDF effectively relaxed the paravertebral muscles via reducing the mechanical pressure, reconstructing motion control mode, transferring an appropriate load between muscle active system and passive system. After 2-level ACDF, the FRR and the normalized EMG RMS values of each phase were improved. However, the overall improvement trend was not ideal compared with that of 1-level ACDF with the FRP recovery rate of only 16.67% at 12 months postoperatively, indicating that the increase of fusion segments would aggravate the damage of the passive structures, and further affect the functional recovery of cervical paravertebral muscles. Interestingly, although the neck VAS decreased, JOA scores increased and NDI decreased, we observed normalized EMG RMS values in each phase, as well as decreased FRR after 3 or 4-level ACDF. It is suggested that although the spinal cord and nerve symptoms were effectively relieved, the passive system was damaged much severer in 3 or 4-level ACDF than that of 1 and 2-level ACDF. The cervical paravertebral muscles recruited more muscle fibers, and more extension moment was needed to compensate in the relaxation phase. Yoo et al. [37] showed that although long-term computer workers do not have neck pain, the FRP also disappears due to the degeneration and destruction of the cervical passive system, suggesting that the passive system dysfunction is more likely to affect the cervical FRP than the neck pain. It is also suitable to explain the relieved pain, but increased fusion segments and aggravated destruction of the passive system. There is no effective coordination reflex among the passive system, the neural regulation system and the muscle active system, which cannot provide a normal movement for cervical mechanical activities. Limitations of postoperative cervical mobility (C2-7 ROM) are observed as well. In addition, the weight of the internal fixation device used in ACDF would become the potential load of the passive system. Sarti et al. [38] found that a light load does not effect on FRP, whereas a greater load decreases the FRR and increases the normalized EMG values, indicating the presence of a load threshold for FRP. The lower potential load of single-level ACDF than that of multi-level ACDF may be attributed to the individualized recovery of postoperative FRP in patients with cervical spondylosis. In conclusion, whether the passive system damage increases or the potential load increases, the paravertebral muscle electromyographic activity increases and FRP disappears during the flexion relaxation test. FRP is normally recovered only by reconstructing the normal coordinated reflection and appropriate load transfer. It indirectly showed that the passive system plays an important role in FRP, which strongly supports the passive structures hypothesis [27, 38, 39].

In addition, a significant correlation was identified between the overall cervical mobility (C2-7 ROM) and the FRP before and after ACDF. Previous studies have shown a more significant correlation between ROM and FRP compared with pain predictors, indicating that the normal cervical spine activity is favorable to FRP [40]. In clinical practice, the change of the cervical paravertebral muscle function can be well predicted by the cervical mobility, which further guides the rehabilitation treatment after ACDF.

Limitations

Several limitations should be noted. First of all, the small sample size and short follow-up period may influence the credibility of our results. Secondly, clinical and radiological evaluation indexes were scant, which may influence the evaluation on the clinical improvement, the accurate change of the cervical mobility, and the correlation with the FRP. Finally, the potential degeneration of the paravertebral muscles before operation and postoperative rehabilitation treatment are not analyzed, leading to potential biases. Previous studies have shown the effect of the potential changes of the paravertebral muscles before operation and the postoperative functional rehabilitation on the paravertebral muscles [7, 41]. In the future, multi-center studies with a large sample size and long follow-up period are needed to further explore the potential changes of paravertebral muscles after single-level or multi-level ACDF, thus validating our current findings.

Conclusion

1-level ACDF could normalize the FRP of cervical paravertebral muscles. The normalization of the FRP after 2-level ACDF was not ideal compared with that of 1-level ACDF. However, 3 or 4-levels ACDF could aggravate the SEMG activity of cervical paravertebral muscles and worsen the function of cervical paravertebral muscles. It strongly supports the passive structures hypothesis. These findings may influence the clinical decision-making one single-level and multi-level cervical degenerative diseases and the guidance of postoperative rehabilitation of cervical vertebrae.

Abbreviations

FRP

flexion relaxation phenomenon

ACDF

anterior cervical discectomy and fusion

CES

cervical erector spinae

VAS

Visual Analogue Scale

JOA

Japanese Orthopaedic Association

NDI

Neck Disability Index
C2-7 ROM
C2-7 range of motion
SEMG
surface electromyography
FRR
flexion relaxation ratio
LES
lumbar erector spinae muscle
STROCSS
Strengthening the Reporting of Cohort Studies in Surgery
RMS
root mean square
MVIC
maximum voluntary isometric contraction

Declarations

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Authors' contributions

PFH and DL participated in study design, experimentation, data analysis and manuscript writing. FY, JXW, LPZ and QH helped in the study design, surgery and manuscript drafting. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated during this current study are available from the corresponding author upon reasonable request.

Ethical approval and consent to participate

The study respected the principles of the Helsinki Declaration and it was approved by the Ethics Committee of The Affiliated Hospital of Southwest Medical University and in accordance with the

standards of the National Research Council. All patients signed a written informed consent.

Consent for publication

Not applicable.

Competing Interest

No conflict of interest for all authors regarding this paper.

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Figures

Figure 1

X-ray preoperative 12 months: (A) 1 level ACDF; (B) 2 levels ACDF; (C) 3 levels ACDF; (D) 4 levels ACDF

Figure 2

Surface electromyography of single-level and multi-level ACDF preoperative 3 days, postoperative 12 months. (E) 1 level ACDF preoperative 3 days; (F) 1 level ACDF postoperative 12 months; (G): 2 levels ACDF preoperative 3 days; (H): 2 levels ACDF postoperative 12 months; (I): 3-4 levels ACDF preoperative 3 days; (J): 3-4 levels ACDF postoperative 12 months

Figure 3

Changes of the flexion relaxation ratio (FRR) from preoperatively (Pre) to postoperatively (Pos) after ACDF

*Statistically significant (P<0.05)

Figure 4

Changes of the normalized SEMG RMS values of each phase from preoperatively (Pre) to postoperatively (Pos) after ACDF: (K) phase 1, the starting phase; (L) phase 2, the complete flexion phase; (M) phase 3, the sustained flexion phase; (N) phase 4, the extension phase

Figure 5

Significant correlations between changes of FRR and C2-7ROM outcomes 12 months after ACDF. (O) 1 level ACDF; (P) 2 levels ACDF; (Q) 3-4 levels ACDF