Percutaneous plasma disc decompression through a lower surgical approach for the treatment of cervicogenic headache in patients with cervical spondylotic radiculopathy: A retrospective cohort study

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Abstract. Cervical spondylotic radiculopathy (CSR) is the most common type of cervical spondylosis, frequently accompanied by cervicogenic headache (CEH). Percutaneous plasma disc decompression (PPDD) and pulsed radiofrequency (PRF) are minimally invasive techniques targeting cervical intervertebral discs or cervical nerves, and have been proven to be effective methods for treatment of CSR and CEH. The present study aimed to evaluate clinical efficacy and practicality of percutaneous plasma disc decompression (PPDD) via a lower surgical approach for the treatment of cervicogenic headache (CEH) and upper extremity radicular pain by analyzing clinical outcomes of patients with cervical spondylotic radiculopathy (CSR) undergoing PPDD and pulsed radiofrequency (PRF). Clinical data of patients with CSR who received PPDD (n=79) or PRF (n=92) at Shanghai Traditional Chinese Medicine Hospital (Shanghai, China) and Jiashan County People's Hospital (Jiaxing, China) from January 2022 to December 2022 were retrospectively collected and analyzed. The surgical site and procedure, bleeding volume, preoperative analgesic use and upper extremity symptoms, history of nerve block treatment and duration of disease were recorded, as well as relevant postoperative complications (infection, hematoma, nerve injury). The therapeutic effects [NRS (numeric rating scale) and NDI (neck disability index) score, and CEH remission rate at 1, 3 and 6 months after treatment] of both surgical methods were investigated using the telephone follow-up. CEH remission rates at 1, 3 and 6 months after surgery in the PPDD group were significantly higher than in the PRF group (78.8 vs. 43.5, P=0.016; 84.8 vs. 34.8, P=0.003 and 75.8 vs. 26.1%, P=0.005, respectively). The PPDD group showed higher NRS scores than the PRF group at 1 month after surgery (3 vs. 2, P<0.0001) and lower NRS scores than the PRF group at 6 months after surgery (2 vs. 3, P<0.0001). NDI scores in the PPDD group were significantly lower than those in the PRF group at 1, 3 and 6 months after surgery (15.49 vs. 20.05, P=0.002; 16.06 vs. 20.10, P=0.003 and 9.90 vs. 13.80, P=0.001, respectively). There was no significant difference in postoperative complication rate between the two groups (P>0.999). PPDD could significantly relieve CEH symptoms and upper extremity radicular pain in patients with CSR treated via a lower surgical approach and PPDD was more effective than PRF for long-term CEH remission and pain alleviation.

Introduction

Cervical spondylotic radiculopathy (CSR) is the most common type of degenerative disease of the cervical spine, accounting for 60-70% of all cervical spondylosis cases. This disease is characterized by upper extremity pain and numbness (1). Mechanical compression of nerve roots and release of neuroinflammatory nociceptive factors (2) are the primary causes of upper extremity pain. Cervical disc herniation (postero- and anterolateral) is the primary reason for the compression of nerve roots (3) and also stimulates cervical sympathetic nerves, restricts cervical mobility and induces symptoms (such as headache, vertigo and chest tightness) (4), thereby impacting quality of life (5). Cervicogenic headache (CEH) may occur with CSR, however the incidence rate of CEH within CSR is elusive (6). One of the most common reasons is that CEH is not frequently diagnosed in the context of CSR. Additionally,

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CSR is associated with lower cervical vertebra, while CEH is associated with upper cervical vertebra (7).

The present study aimed to investigate use of minimally invasive surgery through a lower surgical as treatment for both CEH associated with upper cervical vertebra and CSR associated with lower cervical vertebra.

CEH may be anatomically associated with CSR. CEH is defined as pain perceived in any area of the head caused by a primary nociceptive source in musculoskeletal tissues innervated by cervical nerves (6). CEH may occur alone or with radicular symptoms (6) and its pathogenesis is complex, because it is associated with the trigeminal nucleus and internal cervical nerve, as well as intracervical pressure transmission. Studies have shown that nerve convergence in the cervical trigeminal nucleus is one of the mechanisms of CEH pathogenesis (7,8); other pathogenic mechanisms includes pressure transmission within the upper cervical joint complex (7). Dysfunction of the cervical joint complex produces abnormal tension on the spinal dura, leading to pain associated with CEH (9). The treatment target for CSR is primarily C4-C7 (lower cervical spine) (10). By contrast, CEH is mainly caused by lesions in the higher cervical spine (C1-C3) (11) and the treatment sites are predominantly in the upper cervical spine, and traditional treatment methods using upper cervical techniques typically yield favorable outcomes (12,13). However, clinical trials have demonstrated that lower cervical disc herniation may cause CEH and may be achieved via convergence of pain transmission from lower cervical nerves to the cervical trigeminal nucleus and nucleus caudalis (11,14). The NDI score of CEH before and after treatment (2.32 vs. 0.62) with upper cervical technique such as anterior cervical fusion has been reported (15). For headache neck disability index (NDI) scores, 66.7% of patients report a grade 0 rating at 3 months post-surgery, but this decreases to 60% at 6 and 40% at 12 months post-surgery (14). According to the aforementioned studies, CEH remission rate of upper cervical techniques is slightly higher than lower cervical techniques at 3 months after surgery; however, the sample size of lower cervical techniques for CEH therapy study was relatively small (n=12) and CEH remission rate assessment at 6 months after surgery was not reported so the results need further verification in the future. CEH and lower cervical disease, such as CSR, may be simultaneously treated through a lower surgical approach. However, the traditional upper surgical approach for CEH cannot achieve this combined treatment.

It is necessary to find robust surgical approaches for both CSR and CEH. For CSR, surgical treatments include anterior cervical discectomy and fusion (ACDF), anterior or posterior cervical foraminotomy, percutaneous plasma disc decompression (PPDD) and pulsed radiofrequency (PRF) (14,15-20). Compared with ACDF and foraminotomy, PPDD and PRF both possess advantages of smaller incision, faster recovery and less anatomical impact and have been utilized in the treatment of CEH and CSR (21,22). PRF induces neuromodulation by providing a low-energy electric field to nerve tissues and microglia, improving excessive nociceptive signal transmission with precise localization (23). By contrast, PPDD ablates the herniated nucleus pulposus using plasma, effectively preventing recurrence. Thus, PPDD can effectively relieve compression of nerves and tissue (24). To the best of our knowledge, however, no studies have assessed these types of surgery for simultaneous improvement of CEH and upper extremity radicular pain through a lower cervical approach. Therefore, the present study aimed to investigate the efficacy and safety of PPDD and PRF through a lower cervical approach in relieving CEH and radicular pain of patients with CSR by analyzing clinical outcomes.

Materials and methods

Study population. The present study was approved by the Ethics Committees of Shanghai Traditional Chinese Medicine Hospital (Shanghai, China; approval no. 2023SHL-KY-85-01) and Jiashan County Hospital of Traditional Chinese Medicine (Jiaxing, China; approval no. 2023007). The study was registered in the Chinese Clinical Trial Registry database (registration no. ChiCTR2300074113). Informed consent was obtained by recorded verbal agreement.

Clinical data were retrospectively collected from patients with CSR (with or without CEH) who received PPDD (n=90, mean age, 56±12); age range (40,71), male: n=36, female: n=54) or PRF [n=95, age:54±11; age range (39,69), male: n=38, female: n=57] in the aforementioned hospitals between January 2022 and December 2022. The electronic medical record retrieval system was used to collect patient data and surgical information was collected from surgical records.

Inclusion criteria were as follows: i) Diagnosis at the time of admission of CSR with or without CEH; ii) computed tomography and magnetic resonance imaging of the cervical spine showed signs of nerve root compression due to cervical disc herniation; iii) surgical therapeutic target was the C5-C8 nerve root (PRF) or C4-C7 disc (PPDD) and iv) patient was fully compliant with the study protocol, including attending all scheduled visits and understanding NRS. Exclusion criteria were as follows: i) Combination of free disc, severe spinal stenosis and calcification of the fibrous annulus, ossification of the posterior longitudinal ligament, carpal tunnel syndrome or frozen shoulder; ii) combination of paraplegia or partial paralysis, cervical fracture or dislocation, and cervical instability; iii) history of other surgery and iv) patients with psychosocial or communication disorders. CEH was diagnosed according to Cervicogenic Headache International Study Group criteria as follows: i) Precipitation of head pain by neck movement and/or sustained awkward head positioning or by external pressure over the upper neck in the presence or absence of ii) restriction of the range of motion in the neck and iii) ipsilateral neck, shoulder, or arm pain of a rather vague non-radicular nature (25,26).

The sample size was calculated using the PASS 15.0 software (ncss.com/software/pass) (two independent proportions). The effect size (CEH remission rate at 6 months) obtained from a pilot study (data not shown) with 20 patients was PPDD)=0.76 and PRF)=0.51. A total of ≥144 patients (n=72/group) was required to detect the difference between the two groups with at least P1=0.76, P2=0.51, 80% power, 20% follow-up loss rate and type 1 error of 0.05.

Surgical techniques

PPDD. The low-temperature (40-70˚C) ablation of the protruding part of the intervertebral disc was conducted by percutaneous insertion of the plasma knife head under X-ray

fluoroscopy. The needle tip was accurately inserted into the intervertebral disc, followed by plasma ablation for 30 sec, intermission of 150 sec, shrinking for 30 sec+ intermission of 150 sec.

PRF. Under X-ray fluoroscopy, the tip of the radiofrequency trocar needle was positioned near the diseased nerve and pulse modulation was performed at 40 V. The needle tip was located at the nerve root of the intervertebral foramen and the sensory and motor nerves were tested. The radiofrequency temperature was ~42˚C and PRF time was ~4 min.

Patient data. The age, sex, body mass index (BMI), preoperative analgesic use and upper extremity symptoms, history of nerve block treatment and duration of disease were collected.

Surgical data. The operation site, bleeding volume, operational process, NRS score and NDI score of upper extremity radicular pain and CEH events before surgery were collected.

Clinical follow-up. Primary outcomes were CEH remission rate at 6 months after treatment; secondary outcomes were CEH remission rate at 1 and 3 months after treatment, NRS and NDI score at 1, 3 and 6 months after treatment and postoperative complication rate. NRS and NDI score of upper extremity radicular pain and CEH remission rate at 1, 3 and 6 months after surgery were recorded. Telephone follow-up was performed according to questionnaire including NRS (0-10 points), NDI (10 questions, 50 points), CEH evaluation and evaluation of postoperative complications (postoperative hematoma at the puncture site, infection of the puncture site and intervertebral disc and new cervical nerve injury).

CEH remission was assessed at 1, 3 and 6 months after surgery, including the frequency, duration, and pain degree of CEH. Patients were asked the following: 'How frequently do you experience noticeable CEH daily?', 'what is the duration of these episodes?' and 'to what extent do you feel your headache has improved?' Improvement was defined ≥50% enhancement in ≥2 of these aspects.

NRS (27) was utilized to assess upper extremity discomfort symptoms. Total NRS score was 0-10 points as follows: 1-3, classified as mild pain (barely interfering with sleep); 4-6, moderate pain (partially interference with sleep) and 7-10, severe pain (inability to sleep or waking up in pain during sleep).

NDI scoring system (28) was used to assess the effect of upper limb disease of CSR on daily life. To ensure comprehensive assessment across a wide range of activities, in cases where older patients were not involved in specific activities (such as dancing, driving, reading), similar activities (such climbing stairs, sweeping the floor, watching television or using cell phones) were substituted during the assessment process.

Statistical analysis. Data are presented as the mean ± SD or median and interquartile range. Normally distributed data were analyzed by two-way mixed ANOVA, followed by Bonferroni/Sidak's post hoc test. Skewed data were analyzed using Mann-Whitney U test, followed by Friedman and Nemenyi's post hoc test and Bonferroni's correction. Rate of preoperative analgesic use nerve block and CEH remission (1, 3 or 6 months after surgery) were compared by χ^2 test. For postoperative complications analysis, Fisher's exact test was employed. Linear regression was used to analyze the association between surgical method (PPDD/PRF) and NRS/NDI scores. Multivariate logistic regression analysis was used to assess association between surgical method (PPDD/PRF) and CEH remission rate. For cases that could not be involved in the final statistical analysis due to missing objective data during the follow-up, deletion was performed if the number of cases with missing data was <15. If the number of missing data was >15 but ≤20% of the total, it was attempted to interpolate the missing values. P<0.05 was considered to indicate a statistically significant difference. The statistical analysis was conducted using SPSS 26.0 software (IBM Corp.).

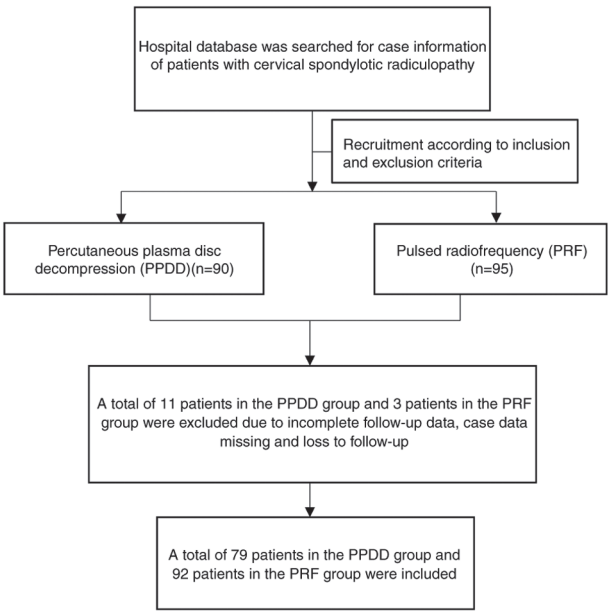

Figure 1. Flowchart of patient selection.

Results

Patients. A total of 95 patients were initially recruited in the PRF group, as well as 90 patients in the PPDD group according to the inclusion and exclusion criteria. A total of 14 cases were excluded due to loss of follow-up and incomplete follow-up data, resulting in 92 patients in the PRF and 79 patients in the PPDD group (Fig. 1).

Baseline characteristics. There were no significant differences in age, sex, BMI, proportion of preoperative medication and numbness, treatment rate, number of cases with upper cervical disc herniation, pain symptoms in the upper extremity and duration of disease between PRF and PPDD groups (P>0.05; Table I).

CEH remission rate and cervical pain score within the two groups. PPDD group had significantly higher CEH improvement rates than the PRF group at 1, 3 and 6 months after treatment (78.8 vs. 43.5, P=0.016; 84.8 vs. 34.8, P=0.003 and 75.8 vs. 26.1%, P=0.005, respectively; Table II). NDI scores in the PPDD group were significantly lower than those in

Table I. Baseline data.

Characteristic	PRF group	PPDD group	P-value
Mean age, years	55±10	54±11	0.99
Sex (%)			0.75
Male	37 (40.22)	29 (36.71)	
Female	55 (59.78)	50 (63.29)	
Mean BMI, kg/m^2	23.50±2.39	24.11±3.03	0.88
Pre-operative analgesic use (%)			0.54
Yes	35 (38.04)	34 (43.04)	
No	57 (62.96)	45 (56.96)	
Nerve block therapy (%)			0.75
Yes	29 (31.52)	27 (34.18)	
No	63 (68.48)	52 (65.82)	
Upper limb symptoms (%)			0.09
Pain	41 (44.57)	46 (58.23)	
Numbness	51 (55.43)	33 (41.77)	
Duration of disease (%)			0.10
≤1 year	68 (73.91)	49 (62.03)	
>1 year	24 (26.09)	30 (37.97)	

PPDD, percutaneous plasma disc decompression; PRF, pulsed radiofrequency.

Table II. CEH remission rate and postoperative complications.

Characteristic	PRF group (n=92)	PPDD group (n=79)	OR (95% CI)	P-value
CEH remission at 1 month post-surgery (%)				
Yes	40 (43.48)	62 (78.48)	4.83 (1.49, 15.61)	0.016[a]
No	52 (56.52)	17 (21.52)		
CEH remission at 3 months post-surgery (%)				
Yes	32 (34.78)	67 (84.81)	10.51(2.92, 37.81)	0.003[b]
No	60 (65.22)	12 (15.19)		
CEH remission at 6 months post-surgery (%)				
Yes	24 (26.09)	60 (75.95)	8.85 (2.60, 30.13)	0.005[b]
No	68 (73.91)	19 (24.05)		
Postoperative complications (%)				0.999
None	86 (94.48)	75 (94.94)		
Infection	1 (1.08)	1 (1.27)		
Hematoma	2 (2.17)	2 (2.53)		
Nerve injury	2 (2.17)	1 (1.27)		

[a]P<0.05, [b]P<0.01. CEH, cervicogenic headache.

the PRF group at 1, 3, and 6 months post-surgery (15.49 vs. 20.05, P=0.002; 16.06 vs. 20.10, P=0.003 and 9.90 vs. 13.80, P=0.001; Fig. 2). PRF group showed higher NRS scores than the PRF group at 1 month (3 vs. 2, P<0.0001). At 3 months after treatment, there was no significant difference (3 vs. 3, P=0.57) and at 6 months after treatment, the PPDD group showed significantly lower NRS scores than the PRF group (2 vs. 3, P<0.0001; Fig. 3). In the PPDD group, CEH remission rate peaked at 3 months, then decreased; CEH remission rate in the PRF group exhibited a continuous downward trend from 1 to 6 months postoperative (Table II). In the PRF group, NDI score at 1 month after surgery showed no significant difference compared with 3 months after surgery (20.05 vs. 20.10, P=0.99); NDI scores between other time points [pre-surgery

Table III. Association between surgical method and primary outcomes.

	CEH improvement rate at 6 months after treatment		NDI score at 6 months after treatment	
Variable	OR (95% CI)	P-value	β (95% CI)	P-value
Age	1.01 (0.95,1.07)	0.70	0.00 (-0.09,0.09)	0.99
Sex	0.21 (0.04,1.06)	0.26	1.65 (-0.41,3.71)	0.12
BMI	0.90 (0.70,1.17)	0.41	-0.14 (-0.49,0.22)	0.44
Upper limb symptoms	1.02 (0.20,5.16)	0.98	0.42 (-1.61,2.45)	0.68
Duration of disease	0.74 (0.18,3.00)	0.67	2.52 (0.36,4.67)	0.02[a]
Pre-operative analgesic use	0.30 (0.07,1.32)	0.21	1.37 (-0.66,3.39)	0.19
Nerve block therapy	0.21 (0.04,1.14)	0.23	1.23 (-0.87,3.34)	0.25
Surgical method	9.87 (2.73,13.30)	0.002[b]	-3.98 (-6.03,-1.92)	0.01[a]

[a]P<0.05, [b]P<0.01. CEH, cervicogenic headache; NDI, neck disability index.

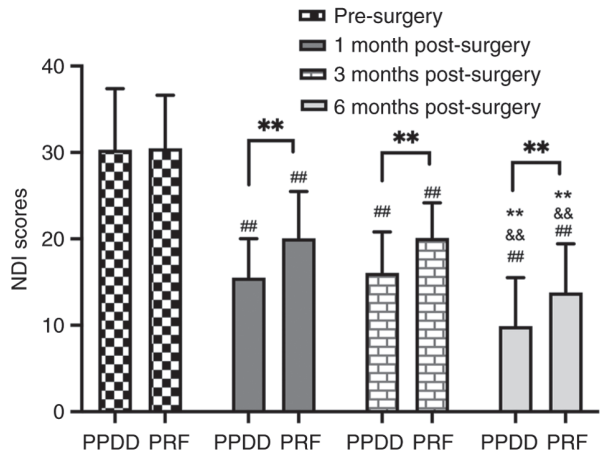

Figure 2. Neck disability index score. ##P<0.01 vs. pre-surgery; &&P<0.01 vs. 1 month; **P<0.01 vs. 3 months; **P<0.01 vs. PRF. PPDD, Percutaneous Plasma Disc Decompression; PRF, pulsed Radiofrequency.

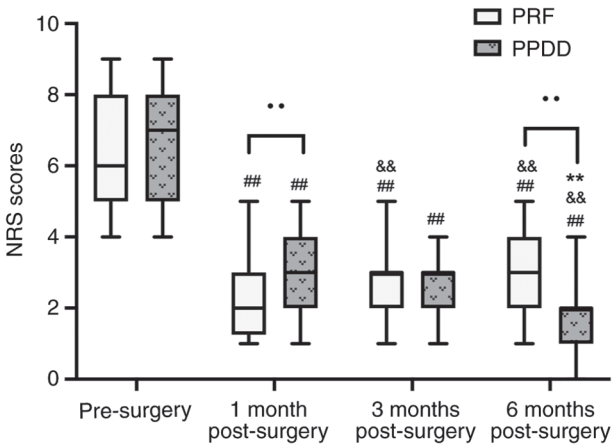

Figure 3. Median Numeric Rating Scale value. ##P<0.01 vs. pre-surgery; &&P<0.01 vs. 1 month; **P<0.01 vs. 3 months; ••P<0.01 vs. PRF. PPDD, Percutaneous Plasma Disc Decompression; PRF, pulsed Radiofrequency.

vs. 1 month (30.46 vs. 20.05, P<0.0001), 3 months vs. 6 months (20.10 vs. 13.80, P<0.0001), pre-surgery vs. 6 months (30.46 vs. 13.80, P<0.0001), pre-surgery vs. 3 months (30.46 vs. 20.10, P<0.0001), 1 month vs. 6 months (20.05 vs. 13.80, P<0.0001)] indicated significant differences In PPDD group, NDI score at 1 month after surgery showed no significant difference compared with 3 months after surgery (15.49 vs. 16.06, P=0.89), the comparison of NDI between other time points [pre-surgery vs. 1 month (30.29 vs. 15.49, P<0.0001), 3 months vs. 6 months (16.06 vs. 9.90, P<0.0001), pre-surgery vs. 3 months (30.29 vs. 16.06, P<0.0001), pre-surgery vs. 6 months (30.29 vs. 9.90, P<0.0001), 1 month vs. 6 months (15.49 vs. 9.90, P<0.0001)] both indicated significant differences (Fig. 2); In the PRF group, NRS score at 3 months after surgery showed no significant difference compared with 6 months after surgery (3 vs. 3, P=0.22); NRS scores between other time points [pre-surgery vs. 1 month (6 vs. 2, P<0.0001), 1 month vs. 3 months (2 vs. 3, P=0.003), pre-surgery vs. 3 months (6 vs. 3, P<0.0001), pre-surgery vs. 6 months (6 vs. 3, P<0.0001), 1 month vs. 6 months (2 vs. 3, P=0.004)] indicated significant differences. In PPDD group, NRS score at 1 month after surgery showed no significant difference compared with 3 months after surgery (3 vs. 3, P=0.42); NRS scores between other time points [pre-surgery vs. 1 month (7 vs. 3, P<0.0001), 3 months vs. 6 months (3 vs. 2, P=0.002), pre-surgery vs. 6 months (7 vs. 2, P<0.0001), pre-surgery vs. 3 months (7 vs. 3, P<0.0001), 1 month vs. 6 months (3 vs. 2, P=0.004)] indicated significant differences (Fig. 3). There was no significant difference in the incidence of postoperative complications between the two groups (P>0.999) (Table II).

Linear regression of NRS and NDI. Surgical methods (PPDD/PRF) and confounders were imported into linear regression to analyze the independent impact of surgical methods on NRS and NDI score and CEH remission. Confounders included age, sex, BMI, preoperative analgesic use and upper extremity symptoms, history of nerve block treatment and duration of disease. Compared with the PRF group, NRS score [β=-1.14, 95% confidence interval (CI; -1.66, -0.62), P<0.0001] and NDI score [β=-3.98, 95%CI (-6.03, -1.92), P=0.011] at 6 months after

treatment were significantly decreased in the PPDD group. Compared with the PRF group, the CEH improvement at 6 months after treatment was significantly elevated in the PPDD group [odds ratio, 9.87, 95%CI (2.73,13.30), P=0.003; Table III]. Therefore, surgical method was an independent factor for NRS and NDI score, and CEH remission rate.

Discussion

The present study indicated that both PPDD and PRF improved CEH and upper limb pain of patients with CSR, however the efficacy and stability of PRF were inferior to PPDD. Compared with 1 month after surgery, the NDI score in the PRF group at 3 months and 6 months after surgery was significantly increased, indicating that patients in the PRF group may require repeated treatment, whereas the NRS and NDI scores in the PPDD group decreased. The CEH remission rate in the PPDD group was higher than that in the PRF group. This indicated that within 6 months of treatment, patients who received PPDD exhibited significantly greater relief from CEH.

PPDD and PRF are both viable options for treating CEH and exhibit varying efficacy in relieving CEH and alleviating upper limb pain. The surgical approach should prioritize PPDD, which directly targets the intervertebral disc by relieving disc pressure. By contrast, PRF primarily targets nerves and surrounding tissues. The occurrence of CEH is associated with the intervertebral disc and intracervical pressure. Prior research has proposed two potential mechanisms for CEH (13): Pressure transmission within the upper cervical joint complex and dural connectivity between the lower and the upper cervical spine. Furthermore, related experiments (13,29) have demonstrated alleviation of spinal cord pressure via cervical laminoplasty, highlighting the role of intracervical pressure in CEH. Therefore, PPDD could significantly alleviate CEH. PRF treatment for CEH may be achieved by regulation of the posterior branch nerve and decreased pressure on the cervical fascia tissue. The radiofrequency scalpel is placed around the posterior nerve, to suppress the transmission of nociceptive electrical signals and decrease pro-inflammatory factor (such as IL-6 and TNF-α) release through pulse current regulation (30) to block pain signal crosstalk between the internal cervical nerve and trigeminal nucleus. PRF can decrease the tension of the cervical fascia by acting on surrounding nerve tissue, thereby decreasing cervical pressure and alleviating CEH. This may be achieved by reducing the levels of Iba1 around the fascia, thereby inhibiting inflammatory cell adhesion and tissue remodeling (31). PRF is commonly used to treat CEH due to its ability to electrically modulate nerves but it does not address intervertebral disc issues. As disc herniation is the primary cause of nerve compression and increased cervical pressure, PRF may be less beneficial for treating CEH associated with cervical disc herniation compared with PPDD (31). This may also explain why the remission rate of CEH in the PRF group was not as high as that in the PPDD group.

As previous studies (11,29) have indicated, CEH is primarily associated with C1-C3 nerves and discs. How PPDD effectively improves both CEH symptoms and upper limb pain via a low cervical spine approach was not clear yet. Another mechanism of PPDD involves the association between anterior vertebral fascia and internal neck pressure. The convergence of C1-C3 cervical nerves in the trigeminocervical nucleus forms the neurophysiological foundation for CEH (11,29). In addition to the anatomical basis of the upper cervical nerves, previous studies highlighted the role of the dura mater in CEH (13,29,32). Hack *et al* (32) demonstrated that the myodural bridge, comprised of the rectus capitis posterior minor muscle, dura mater, occipital bone, atlantoaxial joint and the connecting tissues, transmits forces from the upper cervical joint complex, which includes connective tissue, dura mater, C1 cervical nerve root and rectus capitis posterior minor muscle, to the pain-sensitive dura mater. Lower cervical pressure is transmitted to the upper cervical joint via anterior vertebral fascia, and cervical pressure can act on upper cervical joint complex. Reducing cervical pressure in these areas may be the mechanism by which PPDD via a lower surgical approach improves CEH.

NRS and NDI scores in the PPDD group were significantly decreased compared with the PRF group after treatment. PPDD yielded greater and longer lasting effects than PRF, which may be due to the more stable chemical effects of PPDD compared with the electrical effects of PRF. PPDD exhibits an anti-inflammatory and stress-reducing double effect, including dorsal root ganglion decompression and inactivation of inflammatory factors around the sinuvertebral nerve (33,35). A herniated cervical disc within or outside the intervertebral foramen frequently induces radicular pain in the upper extremity by stimulating or compressing the dorsal root ganglion (33). Compression of the dorsal root ganglion results in abnormal discharge of A and C fibers, potentially underlying development of cervical radicular pain (34). PPDD contributes to mitigation of radicular pain by decreasing disc volume (35) and alleviating nerve root compression via vaporization and retraction of the herniated disc. Furthermore, the sinuvertebral nerve is activated by inflammatory factors, leading to pain. It has been demonstrated that phospholipase A2 (PLA2) exhibits elevated activity in herniated intervertebral disc tissue (36,37). PLA2 has the capacity of exciting nociceptors, resulting in pain in the innervated region, and can also directly stimulate the nerve root, causing chemical radiculitis (37,38). PPDD generates plasma with sufficient energy to disrupt the molecular bonds of PLA2 (38). Consequently, PPDD may alleviate pain by decreasing inflammatory factor release in the intervertebral disc and deactivating pain-inducing factors surrounding the sinuvertebral nerve, including PLA2. By contrast, PRF blocks the transmission of nociceptive stimulation in the nerve. PRF is more rapid and can achieve the inactivation of pain-inducing factors by acting on targets such as neurotransmitters and ion channels (39,40). When the radio frequency electrode is in operation, the blade directly acts on surrounding tissue of the nerve root, enhancing release of GABA neurotransmitters without damaging the nerve (39), and inhibiting the transmission of harmful signals by enhancing the activity of Na^+/K^+ ATP plasma channels, thus quickly exerting analgesic effects (40). While it primarily acts by electrical pulse control rather than directly decreasing pressure on protrusions that cause nerve root compression, the therapeutic effect is relatively limited and symptoms may return.

In summary, PPDD had a dual effect of physical decompression of intervertebral discs and inactivation of chemical

inflammation around the nerves, which makes it more thorough in relieving cervical pressure and peripheral nerve compression, weakening pain nerve conduction of CEH and reducing the generation of pain signal impulses in the upper limb nerve roots. In contrast, PRF mainly acts on local tissue surrounding nerves, exerting its effects via neurotransmitter inactivation and ion channel inhibition. The site of action is limited and there is no deep pressure release effect, which cannot alleviate nerve root compression caused by intervertebral disc herniation. Its analgesic and anti-inflammatory effects are limited. CEH and upper limb pain are associated with nerve compression and release of inflammatory cytokines around nerves.

There were certain limitations in the present study. Firstly, there may be risk of selection bias due to the retrospective study design and lack of randomization. Data was not acquired in real-time, which may decrease accuracy. In future research, the inner mechanism of internal cervical pressure conduction should be further investigated, including the association between increased pressure on the cervical fascia and abnormal discharge of pain fibers in the trigeminal nucleus, as well as the impact of lower cervical disc decompression on upper cervical disc pressure, which may facilitate better treatment of CEH and associated types of cervical disease. Further prospective studies with larger patient cohorts remain to be conducted.

In conclusion, PPDD via a lower surgical approach significantly relieved CEH symptoms and upper extremity radicular pain in patients with CSR. In addition, PPDD was more effective than PRF for long-term CEH remission and upper limb pain alleviation.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

SK conceived the study, analyzed data and wrote the manuscript. XQ and JC analyzed data. JW contributed to analysis and interpretation of data. KW conceived and supervised the study. All the authors have read and approved the final manuscript. SK and XQ and JC and JW and KW confirm the authenticity of all the raw data.

Ethics approval and consent to participate

The present study was approved by the Ethics Committees of Shanghai Traditional Chinese Medicine Hospital (No. 2023SHL-KY-85-01) (Shanghai, China) and Jiashan County Hospital of Traditional Chinese Medicine (No. 2023007) (Jiaxing, China). The study was registered in the Chinese Clinical Trial Registry database (registration no. ChiCTR2300074113). Participants provided verbal consent to participate.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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