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CLINICAL ANALYSIS OF MINIMALLY INVASIVE POSTERIOR PERCUTANEOUS ENDOSCOPIC CERVICAL KEYHOLE FORAMINOTOMY FOR NEURAL DECOMPRESSION IN CERVICAL SPONDYLOTIC RADICULOPATHY

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ABSTRACT

Object: Investigating the therapeutic utility and safety of posterior percutaneous endoscopic cervical keyhole foraminotomy (PPECF) in the treatment of cervical spondylotic radiculopathy. **Method:** 40 patients with cervical spondylotic radiculopathy (CSR) who received PPECF treatment at Yangzhou University's Affiliated Hospital between January 2020 and January 2024 were the subject of a retrospective review that assessed operative time, postoperative hospital stay, complications, and recurrence. Prior to surgery, just after surgery, and at the final follow-up, the neck disability index (NDI), visual analog score (VAS), and Japanese orthopaedic association scores (JOA) were compared. Using a modified MacNab grading system, the clinical efficacy was evaluated. **Result:** All 40 patients underwent successful surgery, and substantial statistical differences were observed between the preoperative and postoperative VAS, JOA, and NDI scores. At the last follow-up, one patient had postoperative painful root palsy, but had fully recovered. Thirty-two patients had significant instant relief in their postoperative symptoms. Following surgery, one patient's arm pain and numbness did not significantly improve; nonetheless, the problem was manageable, so further therapy was discontinued. At 97.5%, the modified MacNab grading was considered excellent and good. Neither the perioperative nor follow-up periods saw any complications, such as dural tears, infections, or postoperative hematomas, and none of the patients needed a second minimally invasive or open surgery to treat dissent. **Conclusion:** Comparatively speaking to other posterior surgeries, PPECF treatment for CSR can produce satisfactory clinical outcomes while avoiding cervical spine fusion and maintaining cervical spine movement function with minimal damage to achieve the impact of nerve root decompression. For the treatment of CSR, PPECF is a minimally invasive, safe, and successful surgical technique.

KEYWORDS: Cervical spondylotic radiculopathy; keyhole surgery; posterior percutaneous endoscopic cervical surgery; minimally invasive spinal surgery; clinical efficacy.

Cervical spondylotic radiculopathy (CSR) is one of the most common types of cervical spondylosis, usually caused by compression of cervical nerve roots due to degenerative changes in the cervical intervertebral disc and its secondary pathological changes. The symptoms of most of these patients can be relieved through conservative treatment, but this does not seem to reverse the degenerative changes in the intervertebral disc, and some still require surgical intervention.[1] The gold standard for surgical therapy of cervical spine instability (CSR) is currently anterior cervical discectomy, decompression and fusion (ACDF).[2,3] However, ACDF has drawbacks, including pseudoarthrosis, loss of intervertebral disc height, internal fixation failure, and adjacent segment degeneration.[4] Accurate identification and classification of cervical disc defects have been made possible by advancements in imaging technology and minimally invasive spine surgery. Additionally, nerve root decompression under endoscopy has become feasible. Posterior cervical percutaneous endoscopic keyhole surgery (PPECF) reduces postoperative axial pain and intraoperative bleeding caused by paraspinal muscle damage in traditional open surgery. It has the advantages of less trauma and fewer complications. At the same time, it avoids the disadvantages of ACDF, such as loss of intervertebral height and adjacent vertebral degeneration. Many studies have confirmed that the use of endoscopic technology to treat CSR has

good prospects.[5-8] Our department used PPECF to continuously treat 40 cases of CSR from June 2020 to June 2024, with satisfactory results. We retrospectively analyzed their clinical data and follow-up data, evaluated the safety and clinical efficacy of PPECF, and summarized our understanding of PPECF in the treatment of CSR. The report is as follows.

1 MATERIALS AND METHODS

1.1 Patient selection

A consecutive enrollment of 40 patients with cervical radiculopathy who had PPECF treatment at Yangzhou University's Affiliated Hospital between January 2020 and January 2024 was made. In terms of imaging, symptoms, and signs, all patients displayed single-segment radiculopathy symptoms (shoulder and neck discomfort, unilateral upper limb radiating pain, numbness, with or without muscle weakness). The same spinal surgeon used an endoscopic system to execute each operation, and their medical data were retrospectively reviewed. We carried out this investigation with the patients' informed permission and the Institutional Review Board's clearance. Every procedure followed the 1964 Declaration of Helsinki and its subsequent modifications' ethical guidelines as well as the guidelines set forth by the National Research Committee.

1.2 Inclusion and Exclusion Criteria[9]

Inclusion criteria: 1) Single-segment posterolateral disc herniation and/or foraminal stenosis on computed tomography (CT) and magnetic resonance imaging (MRI), accompanied by typical unilateral single-segment radicular symptoms, are the inclusion criteria. 2) Signs and symptoms that match the results of imaging. 3) Inability to tolerate pain after at least three months of non-conservative treatment.

Exclusion criteria: Spondylotic myelopathy of the cervical spine. 2) Severe disc calcification, posterior longitudinal ligament ossification, or extensive cervical spinal stenosis. 3) Cervical spine surgery's past. The dynamic X-ray of the cervical spine demonstrates cervical instability. 5) Additional ailments: including epidural fibrosis, tumors, fractures, and infections.

1.3 Surgical technique (Figure 1)

Standard tools: An endoscope with an outer diameter of 6.9 mm and an angular separation of 25°, a drill, a working cannula with an outer diameter of 7.9 mm and a bevel opening, a continuous cleansing system with physiological saline solution, a radio frequency probe, and so on.

Surgical procedure: The patient is placed in a prone position after being given general anesthesia, and the head frame is adjusted to set the head so that it is slightly higher than the feet. The "V" point—a point formed by the inner side of the facet joint, the top edge of the lower lamina, and the lower edge of the upper lamina—and the operative gap are marked on the body surface. The operative gap is positioned beneath the C-arm fluoroscopy. Regular drapes and disinfectants are used in the surgery area. On the exterior of the "V" point, the 16G puncture needle was inserted. The skin was sliced by the No. 10 blade at the puncture location, approximately 7 mm in diameter, and the expansion tube and working sleeve were inserted along the guide wire once the C-arm fluoroscopy verified that the puncture position was satisfactory. Again, fluoroscopy verified the channel location. After cleaning the soft tissue, the "V" point was visible through the endoscope. A drill was used to remove part of the yellow ligament and widen the vertebral plate window at the "V" location by grinding off the top and lower borders of the vertebral plate under the endoscope. Fully expose the dura mater sac on one side, explore the axilla and shoulder of the nerve root, separate and expose the protruding nucleus pulposus, and remove it with a nucleus pulposus forceps. If there is stenosis of the nerve root canal, part of the lateral mass can be removed to the outside to decompress the nerve root canal. After full decompression, the nerve root is explored without compression and the dura mater sac is pulsating normally. Radiofrequency hemostasis is performed, the fluid in the surgical field is drained, and the gauze and instruments are counted and the scope is withdrawn. Intradermal suture is performed, and sterile dressing is applied to end the operation.

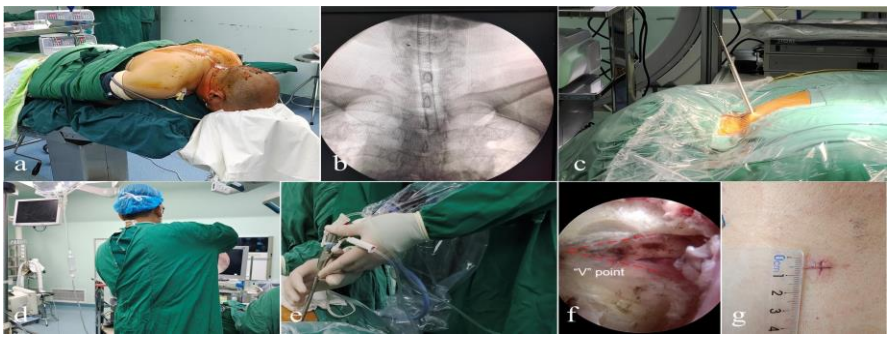

Figure 1: Surgical data.

(a) The patient lies prone on a head fixator, with the head slightly elevated and the feet slightly down. (b) Preoperative positioning of the intercostal space and the "V" point. (c) Insertion of the dilation channel and the operation channel. (d) and (e) Surgical procedure. (f) Exposure of the "V" point under endoscopy. (g) 7 mm surgical incision.

1.4 Postoperative management and clinical evaluation

Following surgery, the incision was regularly treated, and the patient was allowed to go home once their symptoms had considerably improved and there was no visible redness, swelling, or discharge coming from the site. There was a phone follow-up and routine outpatient assessment. The patient's postoperative functional recovery and clinical efficacy were assessed using the cervical spine JOA, NDI, and modified MacNab grading; the VAS was utilized to gauge the extent of pain improvement during follow-up.

1.5 Statistical methods

The statistical analysis was conducted using GraphPad Prism9.0 (GraphPad Software Inc.) and the normalcy test was performed using D'Agostino-Pearson's k2 test. When the data fit the normal distribution, the intra-group comparison was performed using the Paired T test; when the data did not, the Wilcoxon rank-sum test and the Mann-Whitney U test were employed. Statistics were deemed significant if $P<0.05$.

2 RESULTS

2.1 General Information

A total of 40 patients met the inclusion criteria, and the demographic characteristics of all patients are summarized in Table 1. Among the 40 patients, 24 were male and 16 were female. The surgical segments were C3-4 in 2 cases, C4-5 in 7 cases, C5-6 in 25 cases, C6-7 in 5 cases, and C7-T1 in 1 case. The age at the time of surgery ranged from 38 to 86 years old, with an average age of (58.03±12.96 years). The average operation time was (66.18±12.31min), and the intraoperative blood loss was small and could not be measured. The postoperative hospital stay was 2 to 5 days, with an average of (2.7±0.8 days). The follow-up time was 6 to 45 months, with an average of (20.8±12.0 months).

Table 1: General information of patients.

Feature	Value
Total number of patients (n)	40
Age at operation (Average, years)	62.0 (38-86)
Gender (n, %)	
Male	24 (60%)
Female	16 (40%)
Surgical Segment	
C3-C4	2 (5%)
C4-C5	7 (17.5%)
C5-C6	25 (62.5%)
C6-C7	5 (12.5%)
C7-T1	1 (2.5%)
Operation time (Average, minutes)	66.2 (50-95)
Blood loss (ml)	Few and unmeasurable
Postoperative hospital stay (Average, days)	2.7 (2-5)
Follow-up time (Average, months)	20.8 (6-45)
Complications (n, %)	
Transient root paralysis	1 (2.5%)
Dural tear	0
Infection	0
Postoperative hematoma	0
Further second surgery	0

2.2 Clinical Outcomes

All 40 patients underwent PPECF successfully. The symptoms of 38 patients were significantly improved immediately after surgery. One patient had transient paresthesia after surgery, but recovered completely at the last follow-up. One patient had no significant improvement in upper limb pain and numbness after surgery and at the last follow-up compared with preoperative symptoms, but gave up further treatment because it was still tolerable. No complications such as dural tear, infection, or postoperative hematoma occurred during the perioperative period and follow-up period, and no patient required revision surgery due to symptom recurrence.

The VAS, cervical JOA, NDI and modified MacNab grading before, immediately after and at the last follow-up were evaluated and shown in Table 2. The results showed that the postoperative VAS and NDI were significantly lower than those before the operation, with a statistically significant difference ($P < 0.05$); the JOA was significantly improved compared with the preoperative level, with a statistically significant difference ($P < 0.05$). The excellent and good rate of the modified MacNab grading reached 97.5%.

Table 2: Comparison of VAS, JOA, and NDI before and after surgery and modified MacNab grading at the last follow-up.

Follow-up time	Value	P
VAS		
Preoperative	6.9+0.8	
Postoperative	2.0+1.0	P<0.05
Last follow-up	0.7+0.8	
JOA		
Preoperative	13.6+0.7	
Postoperative	15.4+0.8	P<0.05
Last follow-up	16.6+0.6	
NDI		
Preoperative	48.9+4.0	
Postoperative	24.8+1.9	P<0.05
Last follow-up	6.8+3.2	
MacNab grading		
Excellent	38/40	97.5%
Better	1/40	
Good	1/40	2.5%
Difference	0/40	

Note: P < 0.05 indicates a statistically significant difference compared with preoperative.

3 DISCUSSION

The cervical nerve root or nerve root foramen region compression and inflammation are typically the causes of CSR. The most frequent cause is an intervertebral herniated disc that compresses the nerve. About 85/100,000 is the yearly incidence rate.[10] Most patients' symptoms can be eased with conservative treatment, however approximately 30% of individuals still need surgery when conservative treatment fails.[1]

Since Semmes and Murphey initially reported in 1943[11] the connection between cervical disc herniation and particular neurological symptoms, the management of CSR has evolved. The practice of posterior cervical keyhole surgery dates back to Scoville et al.'s proposal in the 1940s. He first put forth the idea of the "keyhole" in 1945. This technique minimizes harm and interference with normal anatomy by using a customized design to choose a direct, short surgical path that gets to the lesion site. In order to successfully relieve the symptoms brought on by nerve root compression and produce good clinical outcomes, the posterior keyhole approach can directly visualize the compressed nerve roots and confirm decompression.[13,14] In order to obtain good decompression of the lateral recess and neural foramen, Henderson et al.[15] employed posterior cervical foraminotomy to directly see the compressed nerve root. Following surgery, 96% of the 846 CSR patients reported significant improvement from their arm pain and paraesthesia symptoms, and 91.5% of patients reported excellent follow-up outcomes. Unfortunately, problems such severe intraoperative bleeding, postoperative neck pain, and muscular spasm appear to be unavoidable because typical open posterior surgery necessitates considerable dissection of posterior cervical muscles and other tissues.[16] However, if the radicular discomfort is bilateral, it might be essential to remove both facet joints in order to adequately decompress. Conventional posterior surgery is also not very effective in treating intervertebral foraminal stenosis and central disc degeneration.

Based on Lahey[19] et al.'s anterior cervical exposure of the esophageal diverticulum technique, Simth and Robinson[18] first proposed ACDF in 1958. Thirteen of the fourteen patients who had ACDF had satisfactory outcomes. Based on this, Cloward[20] resected the damaged intervertebral disc in addition to other sick tissues that were compressing the nerves. According to the findings, 42 out of the 47 patients experienced whole symptom alleviation, 5 cases experienced partial relief, and the rate at which symptoms recovered was quicker than that of a posterior cervical laminectomy. Acute cervical discectomy without fusion[21] also became available shortly after and showed promising outcomes. Greater exposure of the intervertebral area, fewer muscular stress, a decreased risk of postoperative discomfort and muscle spasm, a shorter length of hospital stay following surgery, and smaller incisions are all advantages of ACDF surgery than open posterior surgery. It is highly popular for a variety of reasons, including its capacity to preserve the stability of the cervical spine and remove damaged intervertebral discs to the greatest extent possible.[22 –24] 90% of patients showed a discernible improvement in their postoperative symptoms, according to Herkowitz.[25]

In the long-term follow-up of 122 patients who underwent ACDF, Bohlman[24] discovered that two of the 55 patients with mobility abnormalities had only partially recovered, while 53 of the 55 patients had entirely recovered. 71 of the 77 patients who had sensory loss had their sensation returned. Subsequent research has proven ACDF as the gold standard surgical method for the treatment of CSR, and it is both safe and successful.[2,3] Nevertheless, there are a number of drawbacks to ACDF, including the development of pseudoarthrosis, the loss of intervertebral space height, internal fixation failure, degeneration of the neighboring segment, and access-related difficulties.[4]

The two cervical vertebrae cannot move after ACDF, despite the intervertebral disc being fully removed. Degeneration and illness of adjacent segments are common long-term consequences. Interbody fusion has been demonstrated in several investigations to hasten subsequent stages of degeneration.[26,27] According to a study by Hashimoto[28], following cervical spine fusion, the incidence rate of neighboring vertebral body degeneration was 32.8%, with a 1/4–1/3 chance of developing adjacent vertebral body illness. The range of ACDF problems overall is 13.2%-19.3%. Hemostasis (0.4%–5.6%), postoperative dysphagia (1.7%–9.5%), and hoarseness (0.9%) are the most frequent access-related problems. -3.1%), Horner syndrome (0.6%),

cerebral fluid leakage (1%), and other rare consequences.[29]

Microscopes and endoscopes, as symbols of minimally invasive cervical spine surgery, have led the way in the advancement of minimally invasive spine technology and surgical auxiliary instruments. ACDF has also produced positive outcomes at the same period.[2,3] Using a cadaver model, Roh[30] and Burke[31] et al. showed in 2000 that microscopic cervical discectomy (MED) results in a larger cervical discectomy and a higher percentage of facet resection than conventional posterior open surgery. Range of decompression. 97 out of 100 CSR patients who had MED surgery had satisfactory or outstanding outcomes, according to a research by Adamson et al.[32] The benefits of MED surgery include less surgical trauma, prevention of anterior fusion, and preservation of mobility segments. Fessler's[16] investigation revealed that MED had comparable.

The viability of posterior cervical foraminotomy for the treatment of CSR was prospectively investigated by Rutten[6] et al. using the whole endoscopic lumbar spine system. 87 patients who had posterior cervical complete endoscopic surgery were followed up for two years. It was discovered that 87.4% of the patients had no arm pain at all, and 9.2% of the patients only sometimes experienced pain. In addition to having a low recurrence rate of 3.4% and a less intrusive procedure, the decompression effect is comparable to that of traditional surgery. This was the basis for a randomized controlled study that the author reported the following year[7], in which anterior microsurgical decompression and fusion were performed on 88 patients with CSR. The two approaches did not significantly differ in terms of clinical efficacy or the incidence of problems. There are notable benefits in trauma and postoperative rehabilitation. They think PPECF is a safe, efficient surgical technique that can be employed in place of traditional surgery when the right surgical indications are met. Thirty-three of the 34 patients in the author's study experienced a significant improvement in symptoms, including upper limb numbness and paralysis, shoulder and neck pain, following surgery. At the final follow-up, the excellent and good rate was 97%, which is comparable to the findings of earlier research.[5,8,33] 87% was reported by Kim[33] et al. as a great and good rate. During the 1-year follow-up, 96% of the patients expressed satisfaction with their postoperative recovery, according to Wan[8] et al. Of the 33 patients that Luo et al. reported[5], 32 (97.0%) had an excellent prognosis overall, and every patient's symptoms improved. PPECF does not raise the probability of surgical revision when compared to ACDF.

In addition to having clinical outcomes that are comparable to those of ACDF, it can maintain cervical spine movement function and reduce the likelihood of anterior surgical vertebral body fusion and neighboring vertebral body lesions.[34–36]

Although there were no major issues in our trial, 5.8% of PPECF complications occur overall. Hemostasis, infection, dural rip, and temporary paresthesia are frequent side effects. Epilepsy, headaches, surgically-induced spinal instability, complete spinal anesthesia, and other rare consequences are listed in.[5,6,35,37,38] Damage to the nerve roots during surgery, resulting from severe traction, heat damage, mechanical damage during drilling, etc., is a common cause of transient paraesthesia. According to the author, the remaining bone tissue can be gently removed with the lamina biting forceps after the drill removes the last 1/5 of the thickness of the upper and lower lamina throughout the procedure. The nerve hook should not probe the nerve roots for an extended period of time during the procedure. It can be utilized following the procedure. Auxiliary treatment includes the use of hormones, neurotrophic medications, and dehydration medications. The ligamentum flavum and the dural sac are two examples of soft tissues that are tightly adhered to one another, which can result in tear formation. Generally speaking, conservative care can be used. In order to prevent dural rips, it is important to identify anatomical components carefully during surgery and to separate the ligamentum flavum and the dural sac carefully. A specific water pressure can help maintain the surgical field clear and lessen intraoperative bleeding during PPECF surgery, which is carried out while normal saline is continuously flushed. Incorrect management of the water pressure, however, may result in headaches, epileptic seizures, and postoperative pain in the neck and shoulders. Neck pain is linked to elevated epidural pressure brought on by continuous irrigation systems, according to research conducted during percutaneous intraoperative studies of microscopic lumbar spine surgery.[39]

Consequently, in order to avoid excessive water pressure, it is advised that the saline solution in the continuous flushing system be suspended 1.5 meters above the patient. Compared to typical open surgery, intraoperative bleeding is much lower because of the small surgical incision and minimal injury to the paravertebral tissue. Usually, bleeding originates from the epidural venous plexus. Radiofrequency hemostasis and bone wax packing can both stop minor bleeding. We believe that postoperative infection is uncommon. While they can be used as a preventative measure before, during, or after surgery, I do not advise using antibiotics. Simply adhere to aseptic procedure guidelines while doing surgery, keep the wound dry and clean thereafter, and replace the bandages on a regular basis. successfully prevent postoperative infection. Under either local or general anesthesia, PPECF surgery can be carried out. A benefit of using local anesthesia is that the surgeon can adapt the procedure to the patient's response during the procedure. But when local anesthetic is injected, there are issues with patients' psychological dread and accidental

arachnoid invasion. Complete spinal anesthesia is perhaps caused by the inferior cavity.[38] For the purpose of avoiding nerve damage, the preoperative puncture needle placement, whether for a local or general anesthesia procedure, should not pierce too deeply.

Excessive excision of facet joints and upper and lower laminae may be the cause of cervical instability and cervical axial pain during long-term surgical follow-up. In traditional keyhole surgery, the hole's diameter is 3–4 mm, and the "V" point serves as the operation's core. It is possible to effectively prevent postoperative cervical spine instability by preserving at least 50% of the facet joints.[40] It is possible, in our opinion, to move the opening's center point slightly inward by 0.5–1 mm. One benefit is that it helps prevent excessive facet joint excision, which can cause cervical axial pain and postoperative instability. However, it can prevent harm to the spinal artery and spinal artery. plexus arteriovenous. The protruding nucleus pulposus of CSR is frequently found at the axillary region of the nerve root, based on the author's personal experience. The axillary portion of the nerve root and projecting nucleus pulposus can be examined initially.

In our opinion, PPECF is the most effective surgical method for treating CSR brought on by lateral intervertebral disc degeneration. First off, PPECF is more advantageous than regular ACDF. It creates a keyhole-shaped opening in the cervical vertebral plate, removes the herniated intervertebral disc portion, and keeps the normal portion. This preserves cervical spine movement function at this segment and lowers the likelihood that adjacent vertebral body disease will occur. Second, only posterior endoscopic keyhole surgery among the anterior and posterior cervical spine endoscopic procedures best satisfies the physiological requirements of the human body and is dependable and safe. With posterior endoscopic surgery, the thick posterior cervical muscles are the only organs that must be passed through, as opposed to vital organs like the trachea and carotid artery, as with anterior endoscopic surgery. This method has a shorter length of stay in the hospital after surgery and is safer and more convenient. The postoperative reduction in intervertebral gap height is less, and shorter, less intervertebral disc tissue needs to be removed.[37] Tissue damage is reduced and normal tissue is preserved to the greatest extent possible in all current series, not to mention that surgical risks and complication rates are minimal in all surgical procedures. The results of this approach are also comparable to those of any other technique. In.[41] The nucleus pulposus can be completely removed through the "keyhole" and the intervertebral foramen enlarged, which is a dependable method of achieving nerve root decompression. The majority of CSR can safely and efficiently remove lateral herniated nucleus pulposus, according to one study, which found that the effective and safe distance for removing herniated nucleus pulposus using PPECF is roughly 5.41 mm inward from the outer margin of the dural sac.[42] However, some restrictions associated with this procedure. Forced use of PPECF may result in insufficient decompression and negligible alleviation of postoperative symptoms in cases of central intervertebral disc disease or in combination with calcification of the posterior longitudinal ligament or severe calcification of the herniated nucleus pulposus. This surgical technique also requires the physician to undertake repeated, long-term shoulder lifting procedures, much like completely endoscopic lumbar spine surgery. Ultimately, mastering PPECF surgery can be a challenging process that requires time. The learning curve for this treatment might be shortened by prior endoscopic experience. The following issues with our investigation, which focused mostly on assessing the safety and therapeutic efficacy of PPECF, were present: 1. There were not many cases included. 2. The omission of additional treatment groups from the control group; 3. Inadequate assessment and comparison of pre- and post-operative imaging parameters (intervertebral space height, cervical spine curvature, etc.)

4 SUMMARY

Whether using an anterior cervical approach or a posterior cervical approach, endoscopic or microscope-assisted, CSR surgery plans can greatly reduce patients' symptoms and demonstrate improved performance as technology and science advance. more and more comparable clinical outcomes. The surgeon should carry out the procedure under his or her expertise under the appropriate surgical indications, taking into account the patient's needs as well as their own advantages. The author suggests PPECF for CSR resulting from lateral intervertebral disc disease, but does not rule out the use of other surgical techniques. PPECF is more widely thought to be a secure and useful addition to surgical CSR treatment.

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