Application of anchoring of the projection point on the inner upper edge of the pedicle in minimally invasive posterior cervical foraminotomy (MI-PCF)

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Abstract

Purpose To describe a new modified MI-PCF, and evaluate its feasibility/short-term efficacy.

Method Data from 21 patients with cervical spondylotic radiculopathy who were treated with the modified MI-PCF were collected. Patients' preoperative/postoperative neck and arm pain were evaluated by the VAS, JOA and modified MacNab scores. The postoperative decompression effect was evaluated by CT and MRI. Cervical CT was performed for 3D reconstruction of the patients' cervical spine. A cross section through the intersection of the inner and upper edges of the pedicle was used to measure the distance between the projection point on the inner upper edge of the C3-7 pedicle and the V point (a)/the midline of the spinous process (b). This distance was also measured in human cadavers(c)/(d).

Result The operation was successful in all patients. The mean operative duration was 70.1 ± 20.0 min, and the mean number of fluoroscopies was 4.0 ± 0.9 times. The VAS, JOA and modified MacNab scores were all significantly improved. The values of a, b, c, and d for C3-7 were $1.43 \pm 0.07 \sim 4.98 \pm 0.22$ mm, $14.00 \pm 0.29 \sim 16.35 \pm 0.45$ mm, $1.47 \pm 0.08 \sim 5.08 \pm 0.25$ mm, and $14.04 \pm 0.32 \sim 16.36 \pm 0.43$ mm, respectively.

Conclusion The number of fluoroscopies and the operative duration were reduced by the anchoring of the projection point on the inner upper edge of the pedicle. Overall this study describes a new method for positioning and verification of the V point in MI-PCF.

1. Introduction

Cervical spondylotic radiculopathy(CSR)is a common disease caused by degenerative changes in the cervical spine. CSR accounts for half of all cervical spondylosis cases.¹ Usually, due to protrusion of the nucleus pulposus, hyperplastic osteophytes compress the dural sac and nerve roots to produce the nerve root pain, numbness, weakness and other symptoms in the corresponding arm. Failure of conservative treatment or continuous worsening of symptoms beyond the patient's tolerance necessitates requires surgical treatment. Anterior cervical discectomy and fusion (ACDF) has a significant effect and is regarded as the gold standard of treatment.²⁻⁵ However, intervertebral fusion, and the range of motion of the cervical spine are limited after the operation, and these both contribute to an increase in the force on the adjacent intervertebral discs and an acceleration in the rate of degeneration.⁶⁻¹⁰ As such, many scholars have been continuously seeking new surgical methods, in recent years.

With the continued development of endoscopy and instrumentation, in 2007, Ruetten et al. reported the efficacy of minimally invasive posterior cervical foraminotomy (MI-PCF) in the treatment of CSR. MI-PCF was quickly accepted due to its benefits, which include less trauma, less bleeding, a faster recovery, a similar decompression effect, and the ability to maintain the anatomical structure.^{11,12} Kim proposed that the landmark point under the surgical approach was the V point, that is, where the adjacent cervical lamina and lower edge overlapped on the inside of the facet joint to form a horizontal V-shaped structure

with the top end outward.¹³ Nevertheless, the V point is not fixed and changes dynamically when the neck is extended and flexed. When the neck is flexed, the V point is outside, whereas if the neck is extended, the V point is inside. In addition, there is abundant dense connective tissue (tendons and ligaments) in the neck, which renders it difficult to establish the working channel and increases the likelihood that the end of the channel will deviate from the target point. In this regard, a shallow working channel should be considered since deviation may occur during the operation and the V point may be lost.¹⁴ Therefore, the V point that is seen endoscopically during the operation may not be the true landmark point.

To find the real V point more accurately and quickly, innovative vertical anchoring of the projection point on the inner upper edge of the pedicle under endoscopy view is proposed. The projection point on the inner upper edge of the pedicle is located at the intersection of the upper side and the inner side of the narrowest part of the cervical pedicle (Figure 1). Since this point is a bony structure and does not change in position with movement of the cervical spine, this point can be easily located under C-arm fluoroscopy and can be vertically anchored with a Kirschner wire under the direct view provided by the endoscope. Twenty-one patients were analysed in this study to investigate the safety and efficacy of this technique.

2. Materials And Methods

2.1 Inclusion and exclusion criteria

1) Inclusion criteria:

- a. Patients with typical CSR symptoms, signs and corresponding imaging findings.
- b. Patients who were treated conservatively for at least 4 weeks and whose symptoms had not been relieved or whose symptoms had worsened beyond the tolerance of the patients.
- c. Symptoms of radicular compression caused by a single-segment, one-sided soft disc.

2) Exclusion criteria:

- a. Patients with cervical spondylotic myelopathy.
- b. Patients with a suspected infection or vertebral body tumour.
- c. Patients in whom the cervical spine was clearly unstable.
- d. Patients with cervical deformities.
- e. Patients who had a central type of cervical disc that was herniated.
- f. Patients who had a history of cervical spinal surgery

2.2 General information

According to the inclusion and exclusion criteria, the data of 21 patients admitted to our hospital and treated for CSR by the modified MI-PCF technique from May 2020 to June 2021 were collected. Among these patients, 13 were males and 8 were females. The patient age ranged from 29 to 73 years, with an average age of 54.0 ± 11.8 years, and the mean symptom duration was 18.4 ± 27.3 months.

The study was approved by the ethics committee. The patients and their families were informed of the surgical risks and signed the surgical consent form.

2.3 Surgical techniques

All patients were treated with local anesthesia. With the patient in the prone position, (with the headrest fixed), the cervical spine was slightly flexed and positioned parallel to the ground, then the operative segment was located under C-arm X-ray fluoroscopy. The surgical area was routinely sterilized and draped. The patient's head and shoulders were covered by a waterproof membrane for protection and fixation. Under C-arm fluoroscopy, a puncture needle was inserted into the interlaminar space of the responsible segment, and a 1 cm incision was made to open the skin and deep fascia. A working cannula and endoscope (SPINENODS, Germany) were both placed routinely, the surrounding soft tissue was cleaned, and the outer edge area of the interlaminar space was exposed. Under the direct view provided by the endoscope, a Kirschner wire (2.0 mm) was vertically anchored at the projection point on the inner upper edge of the pedicle, and then C-arm fluoroscopy was performed to confirm the position of the Kirschner wire and verify the position of the V point. When the Kirschner wire was removed the anchor point could be seen with the endoscope. The outer edge of the lamina and a small part of the upper articular process were ground by a drill downward and outward, the grinding range should not extend the anchor point of the projection point on the inner upper edge of the pedicle. At the same time, the relationship between the nerve root, dural sac and intervertebral disc was determined, and the herniated intervertebral disc tissue was removed. After the dural sac and nerve roots were fully decompressed under the microscope, the endoscope and cannula were withdrawn, and the incision was sutured (Figure 2). All patients wore a neck brace for 2 weeks. CT and MRI were performed after the surgery to assess the decompression. The patients wore the a neck brace for protection for 12 to 24 hours after the operation, and the sutures were removed 7 to 10 days after the surgery.

2.4 Follow-up

Immediately after operation, MRI and CT were done to evaluate effective decompression of the nerve root of our procedure. All the patients were followed up through outpatient service and telephone consultation. The fluoroscopy times and VAS for neck and arm pain were recorded and compared with Liao's results.

2.5 Imaging observation

Twenty-one patients were examined by cervical CT. DICOM data were used to reconstruct 3D-CT images of the cervical spine in Mimics. The cross section through the intersection of the upper and inner edges at

the narrowest part of the pedicle was used to measure the values of a and b on the left and right sides respectively (Figure 3).

2.6 Anatomical observation

Digital Vernier callipers (China Taiwan Baogong PD-151) were used to measure the values of c and d on the left and right sides of 19 adult neck specimens (Specimens with cervical deformities, fractures, or a surgical history were excluded to ensure the absence of structural damage to the specimen (Figure 3). The V point was identified by referring to the method described by Cao.¹⁵ Anatomical results were used to verify the accuracy of imaging results.

2.7 Data and statistics analysis

SPSS 25.0 software was used for the statistical analysis. All data were tested for a normal distribution. Then the measured values of the same parameters on the left and right sides of the same segment were compared by paired-sample t test. Differences were considered statistically significant at $P<0.05$. Origin 2017 was used to create the figures.

3. Results

3.1 Clinical data

The average operative duration was 70.1 ± 20.0 minutes, and the average number of fluoroscopies was 4.0 ± 0.9 . The amount of bleeding during the operation was negligible for all patients (Figure 4), in contrast to the traditional method (Table 1).¹⁴

Table 1 Number of fluoroscopies	
	Fluoroscopies
Improved	4.0 ± 0.9
Traditional ¹⁴	12.6 ± 2.0

3.2 Evaluation of the treatment effect

Twenty-one patients were followed up for 3 months, and the results of the efficacy evaluation are shown in Figure 5. Before the operation, one day after operation, and three months after the operation, the mean visual analogue scale (VAS) score for neck and arm pain was 7.9 ± 0.9 , 2.8 ± 0.9 , and 1.6 ± 0.6 , respectively, and the mean Japanese Orthopaedic Association (JOA) score was 11.8 ± 0.8 , 14.7 ± 0.8 , and 16.0 ± 0.8 , respectively. The modified Macnab standard was used to evaluate the clinical efficacy, revealing an excellent result in 17 patients and a good result in 4 patients, thus the percentage of patients with an excellent/good clinical effect was 100%. Compare the improved method's vas score with the

traditional method, there were no statistical difference ($P > 0.05$) (Figure 5, Table 2) ¹⁴. No patients showed obvious complications at the last follow-up.

Table 2
MacNab Scores

	Poor	Fair	Good	Excellent
Preoperative	6	15	0	0
1-day postoperative	0	1	6	14
3 months post-operative	0	0	4	17

3.3 Imaging results

Re-examination of the cervical spine on the first day after the operation showed adequate decompression in all patients. The 3D-CT reconstructions showed that the articular process on the affected side accounted for less than 50% of the total articular process area and that there was no significant impact on the stability of the cervical spine after surgery. (Figure 6).

3.4 CT measurement results

Parameters measured from C3/4 to C6/7 were found to conform to the normal distribution. CT measurement results on the left and right sides of the same segment were tested by paired-sample t test and showed no statistically significant differences ($P > 0.05$). The values of a were $1.43 \pm 0.07\text{mm}$, $1.95 \pm 0.15\text{ mm}$, $3.03 \pm 0.20\text{ mm}$, and $4.98 \pm 0.22\text{ mm}$, and the values of b were $14.00 \pm 0.29\text{ mm}$, $14.40 \pm 0.47\text{mm}$, $15.98 \pm 0.45\text{ mm}$, and $16.35 \pm 0.45\text{mm}$, both with an increasing trend from C3/4 to C6/7.

3.5 Anatomical results

Similarly, there were no significant difference in the anatomical results measured from C3/4 to C6/7 ($P > 0.05$). The values of c were $1.47 \pm 0.08\text{mm}$, $2.06 \pm 0.27\text{ mm}$, $3.06 \pm 0.23\text{ mm}$, and $5.08 \pm 0.25\text{mm}$, the values of d were $14.04 \pm 0.32\text{ mm}$, $14.47 \pm 0.77\text{ mm}$, $15.91 \pm 0.88\text{ mm}$, and $16.36 \pm 0.43\text{mm}$, both with an increasing trend from C3/4 to C6/7 (Figure 8). There were no noteworthy differences in the imaging results (Figure 9).

4. Discussion

For severe single-segment CSR, the long-term curative effect, revision rate and postoperative complications of MI-PCF and ACDF were the same after precise positioning of the V point. ^{12,16} However, MI-PCF reduces dissection of the neck muscles by simply removing the protruding nucleus pulposus, which reduces the postoperative axial symptoms, and the incidence of limited postoperative neck movement as a complication. ^{17,18} Furthermore, this method is capable of preventing accidental injury to the trachea, esophagus, carotid artery and other adjacent tissues in the neck, and avoids the risk of acute

suffocation caused by laryngeal oedema and tracheal compression after surgery.¹⁹ At the same time, MI-PCF retains most of the physiological and anatomical structure, affects the physiological curvature to a lesser extent, and maintains nearly normal overall biomechanical performance.²⁰ Accordingly, this technique has been accepted by the majority of surgeons.

However, this technique requires extremely fine anatomical dissection and is limited by the field of view of the cervical spine that is obtained endoscopically. An in-depth understanding of the adjacent structures is important, especially during the search for the V point which is used as the starting point of the abrasion. Since the cervical laminae are small, there is a large amount of soft tissue adhesion between the laminae, which can be and changed in the flexion and extension of the cervical spine. Hence, it can be difficult to find and repeatedly confirm the V point of the surgical segment under C-arm fluoroscopy during the operation. Researchers have proposed that O-arm fluoroscopy could be used for 3D imaging to locate the V point during the operation,^{21,22} and cervical spine lateral mass vertical anchoring has shown promise for use in surgical positioning.¹⁴ The projection point on the inner upper edge of the pedicle is a bony structure, that does not change with dynamic changes in the position of the cervical spine during the operation. After defining this point as the positioning point, the point was found to extend inward by $1.43 \pm 0.07 \sim 4.98 \pm 0.22\text{mm}$ according to the measurement results, and the accuracy of the V point could be verified again. At the same time, this point could be easily found under C-arm fluoroscopy, and the support of expensive equipment such as an O-arm is not required to find this point. It is reasonable to expect that this novel method is ready for popularization.

In MI-PCF surgery, removing the bony structure around the V point by a drill would cause the V point to be lost, which could lead to surgical disorientation. To solve the above dilemma, Liu et al. used a translaminar approach to treat cervical disc herniation.²³ The projection point on the inner upper edge of the pedicle was not lost after grinding. The inside of this point was the V point, and there was no need to look for the V point through the perspective again. Therefore, the average number of fluoroscopies in our study was only 4.0 ± 0.9 , which is significantly less than the previously reported average of 12.6 ± 2.0 . Thus, this technique shortens the operation and reduces the radiation exposure of patients and medical staff.¹⁴

Based on the anatomical observations, the inner side of the V point is adjacent to the dura mater, and the nerve roots passed through the front of the V point, while the vertebral artery is located deep outside of the V point. If excessively deep grinding is performed in this area the vertebral artery may be damaged, the grinding path may deviate from the intervertebral disc and damage the pedicle. Kim et al. reported a case of spinal dural injury caused by the intraoperative drilling process,²⁴ and Stephen et al. reported a case of vertebral artery injury during posterior cervical surgery.²⁵ Based on the above complications, Nkamura S et al. designed an internal retractor to avoid nerve damage, but it was difficult to popularize.²⁶ The technique of anchoring the projection point on the inner upper edge of the pedicle that was used in this study was performed under direct endoscopic vision. Comparatively, this method has the advantage

of avoiding the possibility of iatrogenic injury caused by the Kirschner wire entering the spinal canal, intervertebral space, spinous process, or vertebral artery.

The abrasion range in MI-PCF extended outward to the lateral edge of the pedicle isthmus. To ensure the stability of the facet joint after the operation, the amount that was removed from the articular process on the affected side was less than 50% of the total articular process area.²⁷ Through anatomical and CT measurements, it was concluded that the distance between the projection point on the inner upper edge of the pedicle and the V point gradually increased from C3/4 to C6/7, reaching a maximum at the C6/7 level. In the report by Cao, the range of horizontally outward abrasion from C3/C4 to C6/C7 was 2 mm–5 mm.¹⁵ Therefore, it was feasible to use the pedicle projection point as the critical point for outward abrasion, and this point provided an intraoperative reference for the scope of laminectomy. Using this point avoided both vertebral artery and nerve damage because the position of the nerve root was too low to cause the fenestration to be too large, which could damage the vertebral artery. Meanwhile, the use of this point also prevented excessive abrasion of the small joint area, which could lead to iatrogenic cervical instability postoperatively.

Although the operative duration in this study may not be superior to the results of published papers within the same period, the operative time significantly decreased with improvements in proficiency during the treatment of 21 patients.²⁸ In the future, additional data will be collected from more patients and the efficacy of this method will be compared with that of traditional MI-PCF. Accurate values of α were obtained by on imaging and verified in anatomical specimens. Unfortunately, due to the possibility of damage to normal anatomical structures, differences in the accuracy of measurement tools, and the differences between anatomical and imaging measurements, the data showed differences between the patients and specimens. There were numerous other restrictions during the processing of the specimens and the results that were measured anatomically differed from those measured on imaging. In future studies, physical specimens and corresponding CT scans will be used to further verify our results.

In brief, the modified MI-PCF technique is a safe and effective new surgical treatment for CSR, that involves little trauma and allows rapid recovery. However, this technique still needs improvement, which motivates us to perform continuous optimization towards a targeted, minimally invasive, fast, and easy-to-learn approach.

5. Conclusion

The technique of anchoring the projection point on the inner upper edge of the pedicle is a supplementary step to the MI-PCF procedure. Using this technique, abrasion can be found performed more accurately and quickly, and the number of fluoroscopies, operative duration, and radiation exposure of patients and medical staff can be greatly reduced. Additionally, the possibility of iatrogenic damage caused by inaccurate recognition of the anatomical structures as well as the learning curve of the surgery can be minimized. This method provides a new approach for location and verification of the V point in posterior

cervical spine endoscopic surgery, and is worthy of further research and more widespread use in clinical work.

Declarations

Ethics approval and consent to participate

This study has been reviewed by Ethic Committee of the Second Hospital of Shanxi Medical University and performed in accordance with the ethical standards laid down in an appropriate version of the 1964 Declaration of Helsinki. The informed consent was obtained from the participant.

Consent for publication

Not applicable.

Availability of data and materials

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

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Kai Wang: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Visualization.

Bin Zhao: Validation, Writing - Review & Editing, Supervision.

Jie Yuan: Methodology, Resources, Writing - Review & Editing.

Chaojian Xu: Formal analysis, Investigation.

Ge Fang: Investigation.

Zhenjian Zhao: Investigation.

Yongfeng Wang: Conceptualization, Methodology, Validation, Writing - Review & Editing, Project administration

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Figures

Figure 1

Schematic diagram of the projection points

(a) Schematic diagram of the inner upper edge of the pedicle (b) Schematic diagram of the inner upper edge of the pedicle (c) Anchor diagram (top view) (d) Anchor diagram (rear view) (e) Position of the projection point on the inner upper edge of the pedicle under c-arm fluoroscopy (f) Endoscopic view of the position of the projection point on the inner and upper edge of the pedicle.

Figure 2

Modified MI-PCF

(a) Site of the local anesthesia and puncture point in the surgical area (b) Establish of the working channel to remove the soft tissue from the responsible segment (c) Anchoring of the projection point on the inner upper edge of the pedicle (d) Endoscopic view of the V point (e) Endoscopic view of the lower spine anchor at the projection point on the inner upper edge of the pedicle (f) Endoscopic view of the upper and inner edges of the pedicle (g) Postoperative nerve pulsation.

Figure 3

Schematic diagram of the measurement method

(a,b) 3D-CT measurement (c,d) Anatomical measurement.

Figure 4

Number of fluoroscopies and operative duration.

Figure 5

Evaluation of treatment effect (a)VAS scores for neck and arm pain (b)JOA scores (c) Comparison with the traditional method.¹⁴

Figure 6

MRI before and 3 months after the operation

(a,b) MRI before the operation (c,d) MRI 3 months after the operation.

Figure 7

Imaging measurement results (a) Values of a (b) Values of b.

Figure 8

Anatomical measurement results (a) Values of c(b) Values of d.

Figure 9

Comparison of the imaging and anatomical results

(A) Values of a and c (B) Values of a b and d.