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The influence of 3D printed guide plate-assisted minimally invasive endoscopic foramina surgery on lumbar function and the levels of 6-keto-PGF1α and IL-6 in patients with lumbar intervertebral disc protrusion

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ABSTRACT
To explore the effects of 3D printed guide plate-assisted minimally invasive endoscopic foramina surgery on lumbar function and the levels of 6-keto-PGF1α and IL-6 in patients with lumbar intervertebral disc protrusion. A total of 120 patients with lumbar intervertebral disc protrusion in our hospital from October 2022 to December 2024 were selected and randomly divided into the observation group and the control group, with 60 cases in each group. The control group was treated with conventional foraminal endoscopic surgery, while the observation group was treated with minimally invasive foraminal endoscopic surgery assisted by 3D printing guide plates. The operation time, intraoperative blood loss, number of punctures, number of fluoroscopy sessions, complication rates such as dural tear, and the improvement of JOA score were compared between the two groups of patients with lumbar intervertebral disc protrusion. The operation time of the observation group was shorter than that of the control group (P<0.05), and the complication rates such as intraoperative blood loss, puncture frequency, fluoroscopy frequency, and dural tear were all lower than those of the control group (P<0.05). The improvements in JOA score, 6-keto-PGF1α, and IL-6 levels were all better than those of the control group (P<0.05). 3D printed guide plate-assisted transforaminal endoscopic minimally invasive surgery for patients with lumbar intervertebral disc protrusion is more conducive to improving the lumbar function of patients and promoting the improvement of 6-keto-PGF1α and IL-6 levels.

KEYWORDS
3D printing Minimally invasive endoscopic intervertebral foramen surgery Lumbar intervertebral disc protrusion Lumbar spine function; 6-keto-PGF1α; IL-6

Lumbar intervertebral disc protrusion is a common degenerative disease in orthopedics. After the onset of the disease, patients mainly present with low back pain, nerve root pain and lumbar dysfunction, which seriously affects the quality of life of patients. Although traditional open surgery can effectively reduce pressure, it has large trauma, slow postoperative recovery, and may aggravate the destruction of lumbar spine stability [1]. With the development of minimally invasive surgical techniques, percutaneous foraminal endoscopy has gradually become the mainstream surgical method for treating lumbar intervertebral disc protrusion due to its advantages such as less trauma, less bleeding and faster postoperative recovery. However, foraminal endoscopic surgery has very high requirements for the surgeon's operational accuracy. Especially in patients with complex anatomical variations or the elderly, there are problems such as high risk of intraoperative nerve injury and prolonged operation time, thereby limiting the application scope of this surgery. In recent years, 3D printing technology has provided new ideas for precise minimally invasive treatment through personalized customization of surgical guides. This mode involves constructing a three-dimensional model based on the patient's CT/MRI data before the operation, designing and printing a guide plate that conforms to the individual anatomical structure to assist the surgeon in quickly locating the puncture path and optimizing the surgical approach, thereby reducing the operational difficulty [2-3]. For this purpose, this article selected 120 patients with lumbar intervertebral disc protrusion in our hospital from October 2022 to December 2024 for research. The report is as follows.

1 Data and Methods

1.1 General Information

A total of 120 patients with lumbar intervertebral disc protrusion in our hospital from October 2022 to December 2024 were selected. The inclusion criteria were: (1) No other complications causing low back pain; (2) Those receiving treatment for the first time; Exclusion criteria: (1) There are no contraindications for this minimally invasive endoscopic foramen surgery treatment; (2) Those with spinal cord tumors; (3) Those who did not cooperate were randomly divided into the observation group and the control group, with 60 cases in each group. In the observation group, there were 33 males and 27 females, aged 24-72 years, with an average age of (49.37±4.18) years. In the control group, there were 32 males and 28 females, aged 23-74 years, with an average age of (49.08±4.55) years. The general data of the two groups of patients were comparable (P>0.05).

1.2 Methods

The control group was treated with conventional foraminal endoscopic surgery. The treatment process was as follows: Patients were placed in the standard prone position and general anesthesia was administered. After the anesthesia took effect, the skin in the surgical area was routinely disinfected, and sterile surgical towels were laid successively to establish a sterile barrier. Under the guidance of the intervertebral foramen endoscopic fluoroscopy system of the C-arm X-ray machine, the surgeon confirmed the responsible intervertebral space and the anatomical position of the intervertebral foramen through anteroposterior and lateral fluoroscopy, and marked the horizontal reference line of the intervertebral space on the body surface. The chief surgeon, holding a Kirschner needle, attempted multi-angle punctures under real-time fluoroscopy monitoring. By repeatedly adjusting the direction of needle insertion, he ensured that the needle tip precisely reached the protruding target area of the nucleus pulposus. After determining the optimal puncture path, a 7mm skin incision was made centered on the puncture point. A guide wire was inserted through the incision and the puncture needle was removed. The soft tissue channel was expanded step by step along the guide wire, and finally a working cannula was inserted to establish the surgical operation channel. After re-verifying the accuracy of the cannula position through the foraminal endoscopy system, targeted staining of the protruding nucleus pulposus tissue was performed using methylene blue solution. The endoscopic system was inserted along the working channel. Under high-definition imaging, the morphological changes of the diseased intervertebral disc tissue were comprehensively evaluated. The deformed and protruding nucleus pulposus tissue was removed in stages using a special nucleus pulposus forceps. During the operation, the changes in nerve root tension were continuously monitored. After confirming that the responsible nerve root achieved adequate decompression, 0.9% sodium chloride injection at a constant temperature of 37℃ was used for irrigation of the surgical area to thoroughly remove tissue debris. Local compression hemostasis was achieved using gauze blocks. After confirming that there was no active bleeding, the surgical incision was closed layer by layer with absorbable sutures.

The observation group was treated with minimally invasive endoscopic intervertebral foramen surgery assisted by 3D printed guide plates. Before the operation, 64-slice spiral CT thin-layer scanning was routinely performed to obtain complete imaging data of the lumbar lesion segments. The original DICOM format data of CT was imported into the Mimics 19.0 medical 3D reconstruction software, and the personalized 3D visualization model of the lumbar spine was reconstructed through algorithms such as threshold segmentation and region growing. The puncture path was simulated and optimized on the three-dimensional model. Computer-aided design (CAD) and rapid prototyping (RP) technologies were adopted to plan the individualized percutaneous puncture channel, and the optimal puncture Angle (35°-45°) and puncture depth (45-60mm) were accurately calculated. The design parameters were imported into the reverse engineering software to generate the navigation template that conformed to the anatomical curvature of the body surface. After topological optimization, the MakerBot Replicator Z18 3D printer (Stratasys Corporation, USA) was used for printing with biocompatible photosensitive resin materials. The printing layer thickness was 0.1mm, and the post-treatment adopted ethylene oxide sterilization. In the operating room, patients were placed in the same prone position for general anesthesia. After strict disinfection and covering with towels, the positioning of the surgical area was completed under C-arm fluoroscopy. The 3D printed navigation template is precisely registered with the anatomical landmarks on the body surface through the dedicated positioning holes, and the template guiding sleeve is used to guide the puncture needle along the preset trajectory directly to the target area. After the puncture needle was in place, the subsequent surgical steps were the same as those of the control group: The endoscopic system was inserted through the working channel of the same diameter, isotonic irrigation fluid was used to maintain the clarity of the surgical field, the lesion tissue was cleared by the dynamic planing system combined with nucleus pulposus forceps, the changes of neuroelectrophysiological signals were continuously monitored during the operation, and finally the adequate decompression of the nerve root was confirmed through dynamic assessment under direct vision. After the operation, the incision treatment and hemostasis operation were carried out using the same plan, and 3-0 absorbable sutures were selected as the suture materials. Both groups of surgeries were performed by the same team of senior spinal surgeons.

1.3 Observation Indicators

(1) Compare the operation time, intraoperative blood loss, puncture times and fluoroscopy times of the two groups of patients with lumbar intervertebral disc protrusion; (2) The inflammatory stress responses of the two groups were compared. 5ml of venous blood was collected from the patients before the operation and one week after the operation respectively. The blood was routinely centrifuged at a rotational speed of 3000 r/min for 15 minutes. Then, some of the serum was taken and the level of 6-keto-prostatic cord PGF1α(6-keto-PGF1α) was detected by radioimmunoassay. Meanwhile, the level of interleukin-6 (IL-6) was detected by ELISA. (3) Compare the incidence of complications between the two groups, including: dural laceration, infection, nerve injury, and hematoma; (4) The improvement of lumbar function in the two groups was compared. The lumbar function was determined by the JOA lumbar function score [4], and

the score range of this scoring standard was from 0 to 29 points. The higher the score, the better the recovery of lumbar function in patients with lumbar intervertebral disc protrusion.

1.4 Statistical Methods

The data were statistically analyzed using SPSS 27.0 software. The t-test was used for measurement data and the χ2 test was used for count data. A P value <0.05 indicates a statistically significant difference.

2 Result

2.1 Comparison of operation time, intraoperative blood loss, number of punctures and fluoroscopy times between the two groups

The operation time of the observation group was shorter than that of the control group (P<0.05), and the intraoperative blood loss, puncture frequency and fluoroscopy frequency were lower than those of the control group (P< 0.05), as shown in Table 1.

Table 1 Comparison of Operation time, intraoperative blood loss, number of punctures and fluoroscopy times between the two groups($\overline{x} \pm s$)

Group	Number of cases	Operation time (min)	Intraoperative blood loss (ml)	Puncture times (times)	Fluoroscopy times (times)
Observation group	60	45.34±4.15	67.48±6.45	1.74±0.35	3.75±0.43
Control group	60	57.24±5.05	99.06±8.57	3.94±0.44	7.69±1.08
T-value		14.102	22.807	30.310	26.254
P-value		<0.001	<0.001	<0.001	<0.001

2.2 Comparison of improvements in lumbar function, 6-keto-PGF1α, and IL-6 levels between the two groups of patients with lumbar intervertebral disc protrusion

The improvement of JOA score, 6-keto-PGF1α and IL-6 levels in the observation group was better than that in the control group (P<0.05), as shown in Table 2.

Table 2 Comparison of improvements in lumbar function, 6-keto-PGF1α, and IL-6 levels between two groups of patients with lumbar intervertebral disc protrusion($\overline{x} \pm s$)

Group	n	JOA score		6-keto-PGF1α(pg/ml)		IL-6(mg/L)	
		Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment
Observation group	60	7.36±0.75	19.27±2.68	69.17±5.37	34.63±2.46	154.23±20.42	51.66±4.18
Control group	60	7.41±0.76	14.33±1.45	69.09±5.35	40.39±3.92	154.27±20.46	75.48±5.29
T-value		0.363	12.558	0.082	9.641	0.010	27.367
P-value		0.718	<0.001	0.935	<0.001	0.992	<0.001

2.3 Comparison of the rates of complications such as dural tear between the two groups

The rates of complications such as dural tear in the observation group were all lower than those in the control group (P <0.05), as shown in Table 3.

Table 3 Comparison of complication rates such as dural tear between the two groups Cases (%)

Group	n	Dural tear	Infection	Nerve injury	Hematoma	Complication rate [cases (%)]
Observation group	60	1	0	0	0	1(1.67)
Control group	60	3	2	2	2	8(13.33)
X^2-value						4.324
P-value						0.038

3 Discussion

Lumbar intervertebral disc protrusion is a common degenerative disease in spinal surgery. Foraminal endoscopic surgery is currently a commonly used clinical treatment method for this disease. However, traditional foraminal endoscopic surgery has problems such as difficult puncture positioning, high risk of radiation exposure and a relatively high incidence of complications. The introduction of 3D printing guide plate technology has provided a new path for surgical optimization [5].

The results of this study showed that the operation time of the observation group was shorter than that of the control group (P<0.05), and the complication rates such as intraoperative blood loss, puncture frequency, fluoroscopy frequency, and dural tear were all lower than those of the control group (P<0.05). The improvements in JOA score, 6-keto-PGF1α, and IL-6 levels were all better than those of the control group (P<0.05). It can be seen that 3D printed guide plate-assisted transforaminal endoscopic minimally invasive surgery for patients with lumbar intervertebral disc protrusion is more conducive to improving the lumbar function of patients and promoting the improvement of 6-keto-PGF1α and IL-6 levels. Analyzing the reasons, traditional foraminal endoscopic surgery relies on the surgeon's experience to repeatedly adjust the puncture path during the operation. Especially in high iliac ridge segments such as L5/S1, due to anatomical mutations such as foraminal stenosis and facet joint hyperplasia, multiple fluoroscopy is required to confirm the position of the instruments, resulting in a longer operation time. The 3D printed guide plate builds a three-dimensional anatomical model including nerve roots, blood vessels and facet joints through preoperative CT/MRI multimodal image fusion technology, and simulates the optimal puncture path. During the operation, the guide plate can guide the puncture needle along the preset trajectory directly to the target point, greatly reducing operational errors, and thereby effectively reducing the number of punctures and operation time. Meanwhile, traditional foraminal endoscopic surgery, due to the repeated entry and exit of instruments in and out of the foraminal area, is prone to damage the paravertebral venous plexus and epidural vessels, resulting in a relatively large amount of intraoperative blood loss. The 3D printed guide plate enables the dispersion of operating pressure to the pedicle projection area during the operation, avoiding vascular tearing caused by single-point stress concentration and reducing the risk of bleeding. Meanwhile, traditional foraminal endoscopic surgery relies on dynamic fluoroscopy with a C-arm machine to confirm the position of the instruments, and the number of fluoroscopy operations in a single operation is relatively high. Under the 3D printing guide plate scheme, by importing the original CT data into the 3D printing center before the operation, the establishment of the three-dimensional reconstructed image is completed. Individualized guide plates are designed according to the pinning method. During the operation, the electromagnetic positioning chip built into the guide plate can track the position of the instrument in real time. Combined with the mixed reality navigation system, the virtual path is projected onto the surgeon's field of vision, thereby effectively reducing the number of fluoroscopy operations. In addition, due to the blind area of the visual field and the high risk of instrument accidental contact with the dural sac in traditional foraminal endoscopy surgery, the incidence of complications such as dural tear is also higher. The contact surface between the guide plate used in 3D printing and the intervertebral foramen adopts a bionic curved surface design, which can disperse the operating pressure, maintain a safe distance between the instrument and the dural sac, and is conducive to reducing injuries, significantly lowering the incidence of complications. Moreover, precise decompression guided by the guide plate can avoid excessive traction on the nerve roots and reduce the levels of 6-keto-PGF1α and IL-6 after the operation. The guide plate can simulate the amount of nucleus pulposus removal based on preoperative MRI data, reduce errors, thereby avoiding stress concentration caused by excessive decompression. The annulus fibrosus suture assisted by the guide plate can also better maintain the integrity of the intervertebral disc, which is conducive to maintaining the lumbar function of the patient.

To sum up, 3D printed guide plate-assisted transforaminal endoscopic minimally invasive surgery for patients with lumbar intervertebral disc protrusion is more conducive to improving the lumbar function of patients and promoting the improvement of 6-keto-PGF1α and IL-6 levels.

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