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Original Article

Two-dimensional fluoroscopy-guided robot-assisted percutaneous endoscopic transforaminal discectomy: a retrospective cohort study

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Abstract: Percutaneous Endoscopic Transforaminal Discectomy (PETD) has been widely used for minimally invasive treatment of lumbar disc herniation (LDH), and percutaneous disc target puncture has a steep learning curve and high radiation exposure. Proper technology grafting can improve the surgical procedure and clinical outcomes. The changes brought by grafting surgical robots into PETD are worth investigating. A retrospective analysis was performed on the information of patients who received PETD in our hospital from March 2019 to July 2020. A total of 102 of patients who received 2D-guided robot-assisted PETD were included in Group A, and 102 of patients who received C-arm fluoroscopy-guided bare-handed PETD were included in Group B. The number of punctures, number of fluoroscopies, operation duration, intraoperative anxiety score, complications, and visual analogue scale (VAS) score and Oswestry disability index (ODI) before operation, on Day 1 after operation and at the last follow-up visit of the two groups were compared. All 204 patients received successful operations. Group A received 1.20±0.42 punctures, 10.49±2.16 fluoroscopies and 60.69±5.63 minutes of operation, significantly fewer than the 4.84±1.94 punctures, 17.41±3.23 fluoroscopies and 71.19±5.11 minutes of operation of Group B (all $P<0.05$), and Group A had significantly lower intraoperative anxiety scores and incidence of complications than Group B (both $P<0.05$). Both groups had comparable VAS and ODI scores on Day 1 after operation and at the last follow-up visit, which were both significantly higher than those before operation ($P<0.05$). 2D-guided robot-assisted PETD can enable precise planning of the puncture path, make it easier for operators to complete targeted punctures at pathogenic targets, reduce the number of punctures and fluoroscopies, shorten the operation duration to optimize the operation process, and reduce complications and alleviate intraoperative anxiety for better clinical results. Therefore it mayb be a better choice to assist PETD.

Keywords: Lumbar disc herniation (LDH), percutaneous endoscopic transforaminal discectomy (PETD), two-dimensional fluoroscopy-guided, robot-assisted

Introduction

Lumbar disc herniation (LDH) is one of the most common degenerative spinal diseases causing low back pain and sciatica, and discectomy is often required if conservative treatment fails [1]. Percutaneous endoscopic transforaminal discectomy (PETD) is performed under local anesthesia without damaging the lamina and paraspinal muscle tissues. For cases with less trauma and faster recovery, PETD has become a popular minimally invasive operation for the treatment of LDH [2].

Traditional PETD, namely the selective percutaneous transforaminal nucleus pulposus removal uses a 0.63 cm channel and it has two technical difficulties, including the accurate puncture of the disc herniation and the effective decompression of nerve root under the microscope [3]. The precise percutaneous puncture target is the first step for successful PETD. However, since the puncture result highly depends on the experience and skills of the surgeon and repeated punctures are common even for an experienced surgeon under fluoroscopic guidance, percutaneous puncture, un-

doubtedly, increases the risk of radiation exposure and iatrogenic injury [4-7], and repeated adjustments of puncture, furthermore, aggravate the pain stimulation and anxiety of patients under local anesthesia, as well as increases the risk of complications and affects postoperative recovery [1, 8, 9].

The application of surgical robots is a new trend, and it has allowed important breakthroughs in orthopedics, general surgery, urology and neurosurgery since 1988, when robots were first reported to be used in surgical operations [10]. Existing robots approved by the FDA for spinal surgery are Spine Assist (Israel), Renaissance (Israel) and ROSA Spine (France). Tinavi orthopaedic robot was independently developed by China and approved for marketing by the National Medical Products Administration (NMPA) is the world's first surgical robot for orthopedic operations and it has a clinical positioning precision above 1 mm. The application of surgical robots in spinal surgery has shown its unique advantages in reducing radiation exposure and improving the accuracy of implants without being limited by human manual errors [11-13], which well meets the needs of minimally invasive spine surgery (MISS). It is feasible to use it in PETD which is in need of precise percutaneous insertion for better surgical results [13-15]. Few studies have reported on it, so this study will introduce some of our early experience in 2D fluoroscopy-guided robot-assisted PETD.

Materials and methods

Patients

A total of 102 patients with single-segment LHD treated by Tinavi orthopaedic robot-assisted PETD were included in this study according to the inclusion and exclusion criteria from March 2019 to July 2020. These 102 patients were assigned to Group A, and the same number of patients who received the traditional PETD performed by the same surgery team during the same period were assigned to Group B. The PETD surgical indication of the patients were patients showing severe sciatica with serious or progressive neurologic deficits; MRI examination showing reveal disc herniation compressing the nerve root that is related to the patient's neurological findings, and patients who show little therapeutic effect of adequate conservative treatment after 4 to 6 weeks. The study was approved by the Ethics Committee of our medical center (No. 202103063). Written informed consent was obtained from all patients for publication of this manuscript and any accompanying images.

Inclusion and exclusion criteria

Inclusion criteria were as follows: 1. Patients had the imaging finding of LDH at single segment; 2. Patients had radiating pain in one side of the lower extremities; 3. Conservative systematic treatments were ineffective; 4. Those who were over 18 years old and patients who agreed to receive PETD; 5. Patients without severe mental illness or psychological disorder. Exclusion criteria were as follows: 1. Patients who had LDH at multiple segments; 2. Patients who were also with spinal diseases such as lumbar spondylolisthesis, lumbar instability, spinal stenosis and lumbar deformities; 3. Patients who failed the follow-up assessment.

Surgical procedure

2D-guided robot-assisted PETD: Patients in Group A were prostrated on a fluoroscopic carbon fiber operating table, their chest and ileac were protected by a soft cushion, and his/her abdomen was suspended. The surgical robot and the fluoroscopy system were connected, and the robot system was covered with sterile plastic and placed by the operation side to ensure that the mechanical arm could cover the entire operation area (**Figure 1**). The operation area was routinely disinfected and applied with the surgical drape, and the tracer was fixed at the operation segment on the patient's body surface. 2D mode of Orbioc C-arm was used for the anteroposterior and lateral fluoroscopy to collect the information of the operation site and transmit it to the computer system (**Figure 2A**). The surgeon directed the intraoperative robot team to personalize the puncture path (based on the location of LHD) (**Figure 2B**, **2C**). After the mechanical arm of the robot moved to the planned path, its guide looked for the surface puncture point automatically. Stratified local infiltration with 0.5% lidocaine was used for anesthesia, and a 0.7 cm to 1 cm incision was made around the surface puncture point. The sleeve was inserted in with the guide (**Figure 2D**), the puncture needle was applied to the target through the sleeve, and

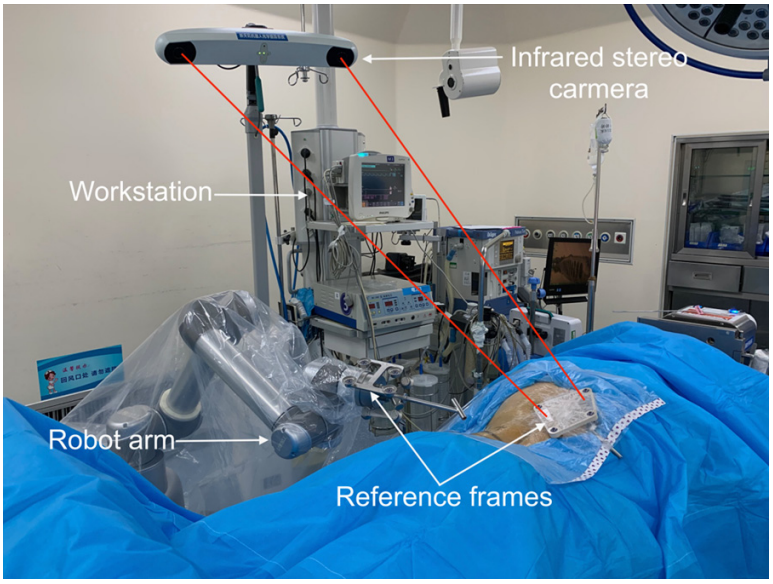

Figure 1. General view of Tinavi orthopaedic robot-assisted PETD.

anteroposterior and lateral fluoroscopy was conducted to verify whether the tip of the guide needle was at the target required by the operation (**Figure 2E**, **2F**). As guided by the needle, the upper articular process was made by step-by-step grinding and drilling. After that, the working channel was placed in, and the imaging system was regulated under the platform for a clear view. The transforaminal endoscopy was then placed into the channel, and normal saline was used for constant rinsing. Radiofrequency coblation was used under the endoscope in the operation field for hemostasis, the working channel was rotated to push away and protect the nerve roots and dural sacs, and the forceps were used for fenestration of the posterior longitudinal ligament and fibrous ring. Under the endoscope, different types of nucleus pulposus forceps were used to remove protruding and free nucleus pulposus in the spinal canal and loose nerve root, and the radiofrequency electrode was placed into the disc for multipoint ablation. After that, the electrode was then drawn back to the fibrous ring for heating coagulation. The lamina nibbling forceps were then used to remove the hypertrophic part of ligamenta flava to further loose the nerve roots. Under the endoscope, the bleeding was not active, the nerve roots were loose, and the dural sac pulse was acceptable. After confirming adequate decompression, the patient was asked about the alleviation of symptoms. After confirming alleviation, the transforaminal endoscope and the channel were removed, the skin was sutured, and the wound was bandaged with sterilized dressing. Representative case as shown in the **Figure 3**.

Traditional PETD: All patients in group B were treated with traditional PETD [16]. Under C-arm fluoroscopy, the lumbar midline, the horizontal line of the diseased intervertebral disc and the puncture line were marked, with the surface puncture point about 10 to 12 cm to the center at L4/5 and about 12 to 14 cm to the center at L5/S1 and the inclination angle of the puncture needle between 20 and 40 degrees. Under anteroposterior fluoroscopy, the puncture needle tip was located on the line that linked the inner edges of the upper and lower vertebral pedicles, and under lateral fluoroscopy, it was located on the line that linked the posterior edges of the upper and lower adjacent vertebral bodies. The specific puncture target was slightly adjusted according to the position of LHD. Stratified local infiltration with 0.5% lidocaine was used for anesthesia. The puncture was performed under the C-arm fluoroscopy, and fluoroscopy was repeated and the puncture was adjusted many times until it reached the target required by the operation. The rest of transforaminal endoscopy operation was performed in the same way as that of Group A.

Postoperative treatment

All patients were allowed to get out of bed on Day 2 after operation, and were asked to do straight leg raising exercise of both lower limbs. They were also asked to wear waistbands for 2 weeks, and avoid bowing or loading within 1 month after operation.

Analysis indicators

Intraoperative information: 1. Number of fluoroscopies: Completing one radiation exposure was recorded as one fluoroscopy; 2. Number of

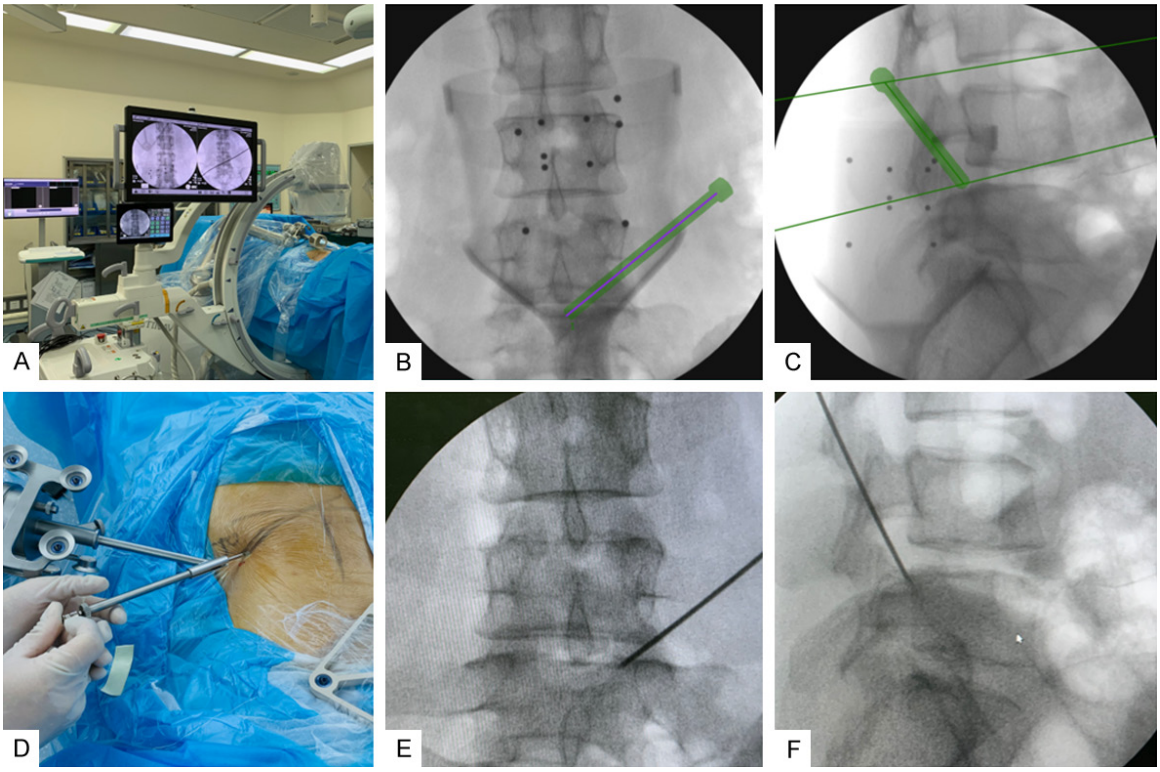

Figure 2. Intraoperative views. A. A tracer was fixed on the body surface of the patient, and the data were collected and transmitted to the surgical robot under 2D mode. B, C. The intraoperative imaging team (robot team) planned the puncture path as directed by the surgeon. D. The mechanical arm of the surgical robot extended automatically along the planned path to the surface area of the patient, and the surgeon inserted the device along the rigid puncture channel suggested by the robot arm. E, F. Fluoroscopy confirms guide needle insertion into target.

punctures: The puncture needle inserted into the skin until resting was recorded as one puncture, every complete puncture trajectory adjustment after that was also recorded as one puncture, and the accumulation of them was recorded as the number of punctures (The differences in surgical procedures between the two groups were analyzed by comparing the number of puncture times); 3. Operation duration: The first fluoroscopy until the completion of skin suture was recorded as the operation duration; 4. Intraoperative anxiety score: The Amsterdam Preoperative Anxiety and Information Scale (APAIS) [17], consisting of 2 questionnaires with 6 items, was used, in which each question is scored 1 to 5 points and a higher score indicates greater anxiety of the patient to receive operation and greater demand for information. This scale mainly reflects a patient's concerns about anesthesia and the operation, it is more targeted, costs less time and is more convenient for intraoperative collection of information.

Postoperative recovery: 1. The visual analogue scale (VAS) score was used to assess the degree of a patient's pain before operation, on Day 1 after operation and at the last follow-up visit. The total score is 10 points, and 0 points indicate no pain and 10 points indicate unbearable pain. 2. The Oswestry disability index (ODI) was used to assess the lumbar function and quality of life. ODI is scored through 10 questions (Pain intensity, Personal care, Lifting, Walking, Sitting, Standing, Sleeping, Sex life, Social life, Travelling) that are scored 0 to 5 points each. The percentage of them is calculated, and a higher percentage indicates severer dysfunction.

Complications: Dural injury, nerve root injury, infection, post-operative dysesthesia (POD) and intervertebral disc residue were recorded as complications of the operation. Intervertebral disc residue: In order to reduce the errors caused by postoperative local edema of tissues and other reasons on the examination

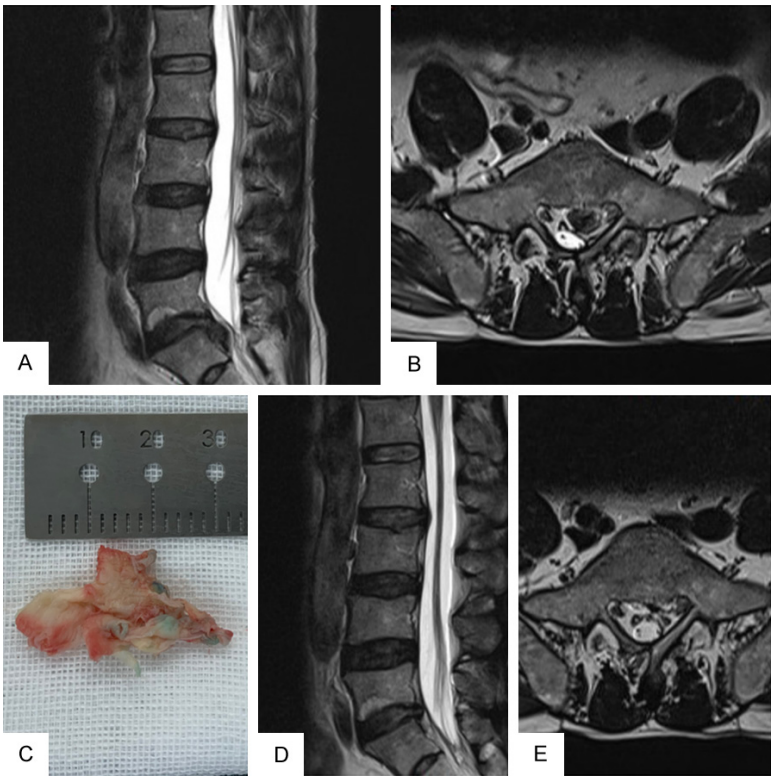

Figure 3. Typical case Female, 35 years old, received 2D-guided robot-assisted PETD for LHD. A, B. Pre-operative MRI suggested protruding of the intervertebral disc at Segment L5/S1 to the left and back. C. Nucleus pulposus tissues removed under the endoscope. D, E. Postoperative MRI suggested complete removal of the protruding nucleus pulposus without residues.

results, the MRI findings of the patients 1 month after operation were compared to their MRI findings before operation. If residual nucleus pulposus tissues were found in the spinal canal or foramen, the patient was recorded as a residual case. The percentage of such cases to the sample base of the group was recorded as the residual rate.

Statistical analysis

SPSS 23.0 statistical software (SPSS, IBM, USA) was used for statistical analysis. Measurement data conforming to the normal distribution (number of fluoroscopies and punctures, establishment time of the puncture channel, operation duration and intraoperative anxiety score) were expressed as mean ± standard deviation. Paired t-test and independent sample t-test were used for intra-group and inter-group comparison, respectively. The enumeration data were expressed as percentages (%), and the Chi-square test was used for the comparison of them between groups. The test level α was set as 0.05 on both sides.

Results

Baseline data

The 102 patients in Group A, including 46 males and 56 females, were aged 44.07± 6.65 years old, of BMI 23.20±0.88 kg/m^2, and of the average follow-up duration of 12.15±1.29 months. Of them, 57 had the operation at segment L4/5 and 45 had the operation at segment L5/S1.

The 102 patients in Group B, including 43 males and 59 females, were aged 44.43± 6.54 years old, of BMI 23.29±0.90 kg/m^2, and of the average follow-up duration of 12.42±1.67 months. Of them, 54 had the operation at segment L4/5 and 48 had the operation at segment L5/S1.

The comparison of baseline data, including the age, gender, BMI, operation segment and average follow-up visit duration, between the two groups showed no statistically significant differences (all P>0.05) (**Table 1**).

Operation results

For the number of punctures, Group A received 1.20±0.42 punctures and Group B received 4.84±1.94 punctures. For the number of fluoroscopies, Group A received 10.49±2.16 fluoroscopies and Group B received 17.41±3.23 fluoroscopies. For the operation duration, Group A was 60.69±5.63 minutes and that of Group B was 71.19±5.11 minutes. For the intraoperative anxiety score, Group A was 14.17±2.48 points and that of Group B was 16.99±2.91 points. Group A had significantly fewer punctures and fluoroscopies, shorter operation duration and lower intraoperative anxiety score than Group B, and all differences between the two groups were statistically significant (all P<0.05) (**Table 2**).

Table 1. Basic characteristics of included patients in both groups

Variable	Group A (n=102)	Group B (n=102)	t/χ^2	*P* Value
Sex (male/female)	46:56	43:59	χ^2=0.179	0.672
Age (years)	44.07±6.65 (29~63)	44.43±6.54 (27~67)	*t*=0.393	0.695
BMI (kg/m^2)	23.20±0.88 (21.50~27.40)	23.29±0.90 (21.40~26.80)	*t*=0.745	0.457
Surgical level (L4/5:L5/S1)	57:45	54:48	χ^2=0.178	0.673
Follow-up (months)	12.15±1.29 (8~18)	12.42±1.68 (8~21)	*t*=1.308	0.192

Table 2. Comparison of surgical data between groups

Variable	Group A (n=102)	Group B (n=102)	*t* value	*P* value
Puncture times	1.20±0.42 (1~3)	4.84±1.94 (1~12)	18.519	0.000
Fluoroscopy times	10.49±2.16 (6~15)	17.41±3.23 (10~26)	18.018	0.000
Operation time (minutes)	60.69±5.63 (51.00~73.00)	71.19±5.11 (55.00~90.00)	13.956	0.000
Interoperative anxiety score	14.17±2.48 (6.00~24.00)	16.99±2.91 (8~26)	7.467	0.000

Table 3. Comparison of clinical outcomes between groups

Variable	Group A (n=102)	Group B (n=102)	*t1* value, *P1* value
Preoperative VAS	6.89±0.94 (5~8)	7.07±1.02 (5~9)	1.285 0.200
Postoperative VAS	2.96±0.73 (1~6)	2.88±0.63 (1~7)	0.819 0.414
VAS at final follow-up	1.55±0.56 (1~4)	1.45±0.62 (1~5)	1.185 0.237
t2 value, *P2* value	33.292 0.000	35.273 0.000	-
t3 value, *P3* value	15.533 0.000	16.259 0.000	-
Preoperative ODI (%)	39.96±4.20 (21.00~67.00)	40.08±4.30 (24.00~72.00)	0.198 0.844
Postoperative ODI (%)	17.93±3.24 (10.00~31.00)	17.83±3.58 (12.00~39.00)	0.205 0.838
ODI at final follow-up (%)	11.02±2.12 (7.00~27.00)	11.23±3.06 (7.00~32.00)	0.559 0.577
t2 value, *P2* value	41.925 0.000	40.118 0.000	-
t3 value, *P3* value	18.027 0.000	14.165 0.000	-

t1 value, *P*1 value: Compare the corresponding data of two groups at the same time node; t2 value, *P*2 value: The postoperative 1 day was compared with the preoperative value; t3 value, *P*3 value: The last follow-up was compared with 1 day after surgery.

Follow-up results and efficacy assessment

All patients were paid follow-up visits, and the average follow-up visit duration was 12.28± 1.50 months.

For the VAS score, Group A was 6.89±0.94 points before operation, 2.96±0.73 points on Day 1 after operation, and 1.55±0.56 points at the last follow-up, and Group B was 7.07±1.02 points before operation, 2.88±0.63 points on Day 1 after operation, and 1.45±0.62 points at the last follow-up. Both groups were significantly improved on Day 1 after operation compared with that before operation, and at the last follow-up compared with that on Day 1 after operation, with the differences being statistically significant (P<0.05), while the differences between the two groups at the same time point were not statistically significant (P>0.05) (**Table 3**).

For ODI, Group A was 39.96±4.20% before operation, 17.93±3.24% on Day 1 after operation and 11.02±2.12% at the last follow-up, while Group B was 40.08±4.30% before operation, 17.83±3.58% on Day 1 after operation and 11.23±3.06% at the last follow-up. Both groups were significantly improved on Day 1 after operation compared with that before operation, and at the last follow-up compared with that on Day 1 after operation, with the differences being statistically significant (P< 0.05), while the differences between the two groups at the same time point were not statistically significant (P>0.05) (**Table 3**).

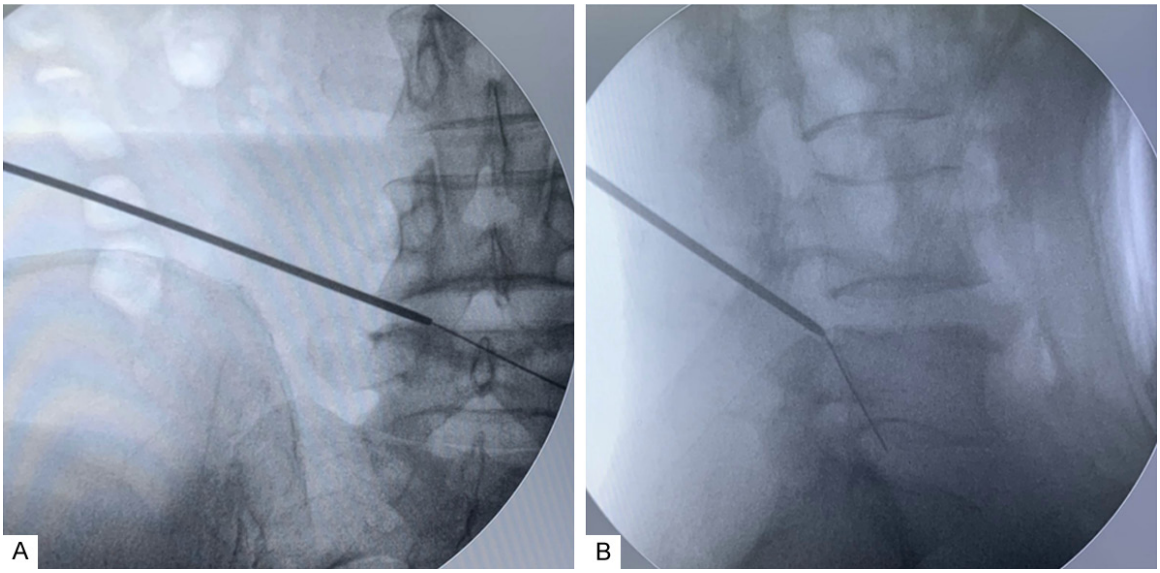

Figure 4. Anteroposterior (A) and lateral (B) X-ray shows the complication of puncture guide needle bending.

Complications

For intervertebral disc residue, Group A had 2 patients (2.0%), significantly fewer than the 9 patients (8.8%) in Group B. None of the patients in either group had nerve root injury, dural sac rupture, infection of intervertebral disc, or postoperative sensory disturbance. The difference in the total incidence of complications between the two groups was statistically significant (χ^2=4.078, P=0.030). Group B had 1 patient with puncture guide needle bending, the guide needle was removed and punctured again, but it did not cause corresponding complications (**Figure 4**). The surgeon performed 12 puncture adjustments on the patient, and the displacement might be caused by the tiredness of the surgeon and less confidence due to repeated puncture failures.

Discussion

In either YESS-assisted PETD [18] or TESSYS-assisted PETD [19], percutaneous puncture into the foramina is the first step. Henmi et al. [20] measured the foraminal distance (the distance between the posterior edge of the intervertebral disc and the ventral side of the facet joint) found that it was shorter than 8 mm in most cases, and surgeons had to do this puncture very carefully since there were nerve roots, dorsal root ganglion (DRG), dural sac and other important structures around it. For safe insertion as far as possible, the puncture angle and depth are adjusted multiple times under the guidance of the fluoroscope in traditional PETD, which, inevitably, prolongs the operation duration and increases radiation exposure. Radiation exposure increases the risk of cancer and cataract and endangers health [4, 6, 21]. In this study, compared with the traditional bare-hand PETD, the 2D-guided robot-assisted PETD had fewer puncture times, fluoroscopy times and operation time. The robot is an iterative product of navigation and has the advantage of high precision, which has been widely verified in assisted pedicle screw placement. In this study, its advantage is reflected in improving the success rate of single puncture. At the same time, the number of fluoroscopies and operation time were positively correlated with the number of puncture, and they also decreased with the decrease of puncture number.

Scholars have used Hello locator [6], CT-guided robot navigation [22] and ultrasound-guided assistance [5] to improve the success rate of puncture and reduce radiation exposure. The puncture assisted by the 2D-guided robot in this Study had a high success rate as that assisted by CT-guided robot and that assisted by Hello locator. However, in the Study, the information of the puncture target and the puncture path could be obtained under conventional anteroposterior and lateral fluoroscopy in 2D

Table 4. Comparison with CT-guided robot and C-arm guided hello

Auxiliary method	2D guided robot	CT-guided robot [20]	C-arm guided hello locator [12]
Puncture times	1.20±0.42	1.00±0.00	1.19±0.48
Fluoroscopy times	10.49±2.16	21.33±3.89	14.03±2.54

mode and could be confirmed in another anteroposterior and lateral fluoroscopy when the puncture was made and reached the target. Therefore, compared with the latter two ways, the puncture in this study had fewer fluoroscopies than 21.33±3.89 in CT-guided navigation-assisted puncture and 14.03±2.54 in C-arm-guided Hello-locator-assisted puncture, while having a similar success rate (**Table 4**). Ultrasound-guided assistance can reduce radiation exposure compared with traditional assistance. It replaces the radiative guiding device with one free of radiation, but it is more complicated to perform, requires a professional ultrasound doctor to assist, cannot eliminate the effects of physiological tremor of the hand on the results as the puncture is made by bare hands after the target is confirmed, and still requires fluoroscopy to confirm whether the puncture reaches the target at last. Compared with ultrasound-guided assistance, a robot provides more stable mechanical arms and requires only the surgeon to insert the guide needle through the rigid puncture channel. Surgical robots are gaining popularity in minimally invasive spinal surgery [13-15], and it is easier to promote them than ultrasound-guided assistance. In conclusion, 2D-guided robot-assisted PETD is the optimal choice for the improvement of the success rate of puncture and reduction of radiation exposure. Besides, robots are reproductive [11, 13, 14], in the sense that they can effectively reduce the influence of varying experience with doctors on the puncture result and are of great significance in promoting the homogenization of operation results.

PETD is very sensitive to the location of the channel because the decompression has to be achieved in a narrow channel. Usually, surgeons need to design different puncture paths to reach the target according to the different locations of LDH. The precision of puncture affects the location of the channel, and is one of the key factors for the success of the operation and prevention of complications [7]. In Ahn's [23] report, the incidence of dural sac injury in 811 patients who received PETD was 1.1% and that of nerve root injury was 0.35% to 0.7%. In Cho's [24] report, the incidence of DRG injury-induced post-operative dysesthesia (POD) was 1% to 6%. In Choi's [25] report, the incidence of intervertebral disc residue was 2.76%. The dural sac and nerve root may be damaged by direct puncture injury and channel compression, while poor channel placement may lead to intervertebral disc residue due to incomplete nucleus pulposus removal. In the Study, 9 patients (8.8%) in Group B had intervertebral disc residue, significantly more than the 2 patients (2%) in Group A, and 1 patient in Group B had guide needle displacement, with the difference in complication between the two groups of statistical significance ($P<0.05$). Some scholars used XMR-assisted (integrating X-ray and MR imaging suite) to plan the skin puncture point and monitor intervertebral disc residue during the operation [26], and others used three-dimensional intraoperative imaging with O-arm to establish the optimal working trajectory to ensure surgical effects [27], both suggesting the important significance of precise puncture trajectory and proper placement of the channel in PETD [3, 7]. The robot system allows planning of the puncture trajectory, and its high precision ensures that surgical devices can reach the targets required under different circumstances of illness as accurately as possible [11-15], so it plays a positive role in ensuring surgical efficacy and reducing complications.

The analysis by Neufeld et al. [28] showed that 30% of elderly patients over 70 years old had mental disorders after surgery under general anesthesia, and the analysis of Seymour et al. [29] showed that 60% of 288 patients over 65 years old had postoperative complications after surgery under general anesthesia. Completing PETD under local anesthesia benefits patients, especially elderly patients, because it can lower the risk of anesthesia, promote postoperative recovery, reduce the length and cost of hospital stay, and detect intraoperative nerve root injury from the instant feedback of patients to enable surgeons to reduce devastating complications. However, such benefits

are accompanied by challenges to patients because in most cases, the puncture in PETD cannot be done at one time and local anesthesia cannot completely eliminate the pain stimulation caused by the puncture, which often requires patients to have strong psychological and pain tolerance. Due to functional disability, pain and other reasons, about 37.6% [8, 30]. LHD patients had developed preoperative anxiety, and patients who received PETD under local anesthesia had severer intraoperative anxiety [9]. Patients having severe intraoperative anxiety had poorer compliance, involuntary physical movements, greater use of narcotic drugs and even surgical interruption, possibly [31]. A high anxiety level also causes the secretion of catecholamine and glucocorticoids in patients to increase, delays tissue regeneration, reduces the number of lymphocytes, increases the risk of infection [32], and increases the incidence of postoperative piriformis syndrome [9]. Literature reports on intraoperative anxiety of patients under conscious local anesthesia are few. In the Study, the APAIS [17] was used to assess the intraoperative changes in patients' mental status, as well as patients' concerns about anesthesia and the operation. The collected data showed that under conscious local anesthesia, Group A had a significantly lower intraoperative anxiety score (14.17±2.48 points) than Group B (16.99±2.91 points), with the difference having statistical significance ($P<0.05$). According to interviews with the patients, the patients could perceive the surrounding environment consciously during the operation, and their preoperative doubts and concerns about safe completion of the operation were carried over to the course of the operation and existed during the whole operation. Patients in Group B received more punctures and had longer operation duration, which not only intensified the pain stimulation during the operation but also aggravated their anxiety. The success rate of puncture of Group A stayed at a high level, and Group A had the operation done more efficiently, bringing extra benefits that reduced intraoperative pain stimulation and anxiety and making it play a positive role in improving intraoperative experience and reducing the use of drugs and psychological intervention.

The Tinavi orthopaedic robot used in the study was equipped with an optical real-time tracker and respiratory motion compensation follow-up control technology, so it had excellent operating precision [33, 34]. However, the Tinavi orthopaedic robot had its limitations in the Study. First, the existing surgical robot had no devices fitting the transforaminal endoscope, causing the punctures into the first three patients in Group A to be adjusted 5, 3 and 2 times, respectively, and the puncture tube failed to match the diameter of the puncture needle of the transforaminal endoscope, causing deviations in the puncture trajectory, so puncture guide needles of better fitting were used in the patients followed and the results were effectively improved. Secondly, the existing surgical robot could only assist the puncture, and later operations under the endoscope still depended on the experience of surgeons. Thirdly, there is a learning curve for every new technology from emergence to popularization, and extra training is required. Fourthly, surgical robots are expensive, and the use and maintenance cost of them is a problem we have to face, which, to some extent, will increase the economic cost of patients and hinder their promotion. Fifthly and theoretically, although the robot system is superior to image-based navigation, it is only an iterative product of the image-based navigation technology and it is less intelligent. Surgical robots are still an emerging technology, and they are to be improved in many aspects. It is believed that with the improvement of intelligence and image-based guiding devices, surgical robot-assisted PETD may have consistent results in some processes of the operation, and surgical robots may be able to be used in the whole course of PETD.

The study is a retrospective study with a small sample size, which might result in biases in the study results and, moreover, radiation exposure details were not measured in the Study. A multi-center, large-sample-size, prospective randomized controlled study is being conducted to verify the safety, feasibility and advantages of 2D-guided robot-assisted PETD in treating LDH.

In summary, the 2D-guided robot-assisted PETD had a significantly higher success rate of one-time puncture, fewer fluoroscopies and shorter operation duration, and its extra benefits could alleviate intraoperative anxiety and

reduce complications. Besides, robots are reproductive in the sense their movement is reproducible, so they can effectively reduce the over-dependence of puncture results on the experience and skills of surgeons.

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Disclosure of conflict of interest

None.

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