Novel targeted puncture technique for percutaneous transforaminal endoscopic lumbar discectomy reduces X-ray exposure

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Abstract. The present study explored a method to reduce X-ray exposure dose and avoid targeted puncture complications in percutaneous transforaminal endoscopic lumbar discectomy (PTELD). A total of 66 patients with lumbar disc herniation were divided into two groups for a controlled study. In the experimental group, 31 patients were subjected to PTELD using a novel targeted puncture technique with application of a lumbar disc herniation target collimator. The remaining 35 patients in the control group were subjected to free-hand targeted puncture PTELD. The number of X-ray fluoroscopies performed intraoperatively, targeted puncture accuracy, visual analogue scale for surgical pain and Oswestry disability index of the two groups were statistically analyzed. The experimental and control groups exhibited a statistically significant difference in the number of X-ray fluoroscopies required during the procedure (P<0.01). The number of successful first targeted punctures was 27 (87.1%) in the experimental group and three (8.6%) in the control group, indicating that the puncture accuracy was higher in the experimental group than in the control group. As for the pain response to outer sleeve insertion (local anesthetic injection through the guide sleeve), the experimental group had 25 mild cases (80.6%), five moderate cases (16.1%) and one severe care (3.2%), whereas the control group had five mild cases (14.3%), 19 moderate cases (54.3%) and 11 severe cases (31.4%). These results demonstrated that the overall pain response of the experimental group was milder than that of control group. Due to a larger puncture deviation, the nerve root was touched by the puncture needle in 12 cases in the control group and resulted in one case of severe postoperative infection. In conclusion, the novel targeted puncture technique guided by a lumbar disc herniation target collimator outlined in the present study is able to markedly reduce X-ray exposure dose in PTELD and limit the surgical risk and pain experienced by patients. Mastering this novel puncture technique may aid those new to performing PTELD.

Introduction

Percutaneous transforaminal endoscopic lumbar discectomy (PTELD) is the most minimally invasive surgical method used to treat lumbar disc herniation (1-4). The procedure possesses the features and advantages of a minimally invasive treatment, including an extremely small incision, little bleeding, light damage and rapid recovery (5-8). PTELD has little effect on the structure of the spinal canal, does not affect spinal stability and forms only slight scar adhesions. PTELD is currently a central focus in spinal surgery research on minimally invasive treatments for lumbar disc herniation.

The first step of PTELD requires the puncture needle to percutaneously pass through the narrow intervertebral foramen, and the puncture needle tip enters into the location of lumbar disc herniation tissue that compresses the nerve root in the spinal canal (also known as the target spot). This process is referred to as percutaneous targeted puncture (9,10). Following this initial step, guide wire is inserted through the puncture needle and a dilating sleeve is inserted under the guidance of the guide wire. The working sleeve is placed in the target spot to effectively remove lumbar disc herniation tissue under full endoscopy to relieve the nerve root from compression. At present, surgeons perform this puncture surgery free-hand, relying on their sense of touch and surgical experience. When conducting PTELD free-hand, multiple X-ray fluoroscopies are required to confirm the locations of the puncture needle tip and the sleeve’s front end and to repetitively adjust the angle of the puncture needle. Therefore, both the operator and patient suffer from high doses of X-ray radiation, which is extremely unfavorable for their health. According to a study by Zhou et al (11), the number of X-ray fluoroscopies performed...
for targeted puncture and sleeve insertion may be as high as 32. Evidence has suggested that the duration of X-ray fluoroscopy may be 1.6-4.5 min, and the X-ray exposure dose for surgeons new to the technique may be even more (12). As X-ray exposure causes damage to the human body, there are few surgeons who are willing to learn this technique. Furthermore, free-hand targeted puncture may have large deviations, which may cause damage to important blood vessels, nerves, the intestinal canal and other tissues, resulting in severe adverse effects. For proficient surgeons with effective sense of touch and rich practical experience (11,13), the free-hand percutaneous targeted puncture technique is able to achieve relatively high accuracy and reduced X-ray exposure. However, for beginners who are not yet proficient, have less effective sense of touch and poor practical experience, percutaneous targeted puncture is a difficulty they are required to overcome in order to master the PTELD technique.

In order to reduce the number of times and dose of X-ray exposure during free-hand targeted puncture and sleeve insertion in PTELD, as well as to increase targeted puncture accuracy and avoid puncture deviation, the present study developed a lumbar disc herniation target collimator and used a newly established methodology to guide the targeted puncture (14) (Fig. 1). This novel technique is able to accurately guide the puncture needle to percutaneously pass through the narrow intervertebral foramen in the first attempt, and enter the location of lumbar disc herniation in the spinal canal. The present controlled clinical study was conducted using the new targeted puncture technique with the application of the lumbar disc herniation target collimator.

Materials and methods

Ethics statement

Patients. Between January and September of 2014, 66 lumbar disc herniation patients were admitted and treated within the Department of Spinal Surgery, Longgang District Central Hospital of Shenzhen (Shenzhen, China). All patients gave their written informed consent prior to participating in the study. The present study was approved by the Ethics Committee of Longgang District Central Hospital of Shenzhen. Patients were divided into two groups based on their dates of birth: Patients whose date of birth was an even number were assigned to the control group and underwent PTELD using a novel targeted puncture technique with application of a lumbar disc herniation target collimator; and patients whose date of birth was an odd number were assigned to the experimental group and underwent PTELD using a novel lumbar disc herniation target collimator.

The present study was approved by the Ethics Committee of Department of Spinal Surgery, Longgang District Central Hospital of Shenzhen (Shenzhen, China). All patients gave their consent to undergo PTELD using a novel lumbar disc herniation target collimator.

The experimental group contained 31 patients, including 20 males and 11 females aged from 25 to 50 years old, with a mean age of 37.5 years. The patients had suffered from lumbocrural pain for 1.5-48 months, with a mean of 14 months of pain. Their lumbocrural pain visual analogue scale (VAS) score was 6.5161±0.9957 and Oswestry disability index (ODI) score was 65.1935±10.9436. The herniated segment was L3/4 in two cases, L4/L5 in 24 cases and L5/S1 in five cases. The control group contained 35 patients, including 19 males and 16 females aged from 28 to 54 years old, with a mean age of 39.7 years. Control patients had suffered from lumbocrural pain for 2-48 months with a mean of 14.3 months of pain. Their lumbocrural pain VAS score was 6.6857±0.9632 and ODI score was 65.7714±10.6470. The herniated segment was L4/L5 in 27 cases and L5/S1 in eight cases. There was no significant difference in age, duration of lumbocrural pain, VAS score and ODI score between the two groups (P>0.01), as exhibited in Table I.

All patients received lumbar anteroposterior and lateral X-ray radiographs, lumbar over flexion-extension X-ray radiographs, as well as imageological examinations of lumbar computed tomography (CT) scans and lumbar magnetic resonance imaging (MRI). All surgeries were performed by the same surgeon and conversation with the patients was maintained during surgery. The surgeon was immediately informed when the patient exhibited lower limb or buttock pain, which indicated that the puncture needle tip had touched the nerve root. If this occurred, the puncture needle was immediately withdrawn to avoid aggravating or causing further damage to the nerves.

Surgical methods

Surgical method for the experimental group. First, the lumbar disc herniation tissue location (target spot) was determined from lumbar X-ray radiographs, CT and MRI images based on the downward displacement of lumbar disc herniation tissue exhibited on sagittal images of CT or MRI scans (Figs. 2 and 3). On lumbar anteroposterior X-ray radiographs, the cranial angle α of the lumbar disc's parallel line was measured on the coronal plane and the value of angle α was the angle that was required to be set for the α angle locator (Fig. 4). On cross-sectional CT or MRI images, line AO for the optimum puncture path from the back side of the waist to the target spot was customized (the path line must not pass the front edge of the iliocostalis, intestinal canal or other tissues that may be injured), and the β angle between the puncture path line AO and the coronal plane was measured. The value of angle β was the angle that was required to be set for the β angle locator (Fig. 5). On the lumbar over flexion X-ray radiographs, the vertical projection point (B) of the target spot was marked on the edge of the skin of the waist, and the distance (d) from the target spot (O) in the spinal canal to its skin projection point (B) was measured (Fig. 6). According to the orthogonal trigonometric function relationship, the distance between the circle center of the α angle locator and the circle center (E) of the β angle locator was calculated as d1=λtgβ and the distance between the target spot (O) and the circle center (E) of the β angle locator was calculated as d2=λ/sinβ.

The patient was asked to lie in the prostrate position on the operating table, and the position was adjusted to allow for lumbar over flexion so that the waist plane was parallel to the floor. The patient was kept immobilized. Bony structures of the subcutaneous lumbar spine were touched and lines between
lumbar spines were marked. A roentgen opaque positioning grid was flatly placed over the skin of the waist, and the first lumbar anteroposterior X-ray fluoroscopy was performed using a mobile C-arm X-ray machine. Following this, the lumbar disc’s parallel line (CD) and the vertical projection point (B) of the target spot were marked on the skin. Disinfection was frequently performed on the skin surface around the surgical area and an aseptic towel was subsequently placed over the skin. The α angle locator was horizontally placed on the skin of the waist so that the circle center of the α angle locator was on the vertical projection point (B) and the diameter of the α angle locator was on the lumbar disc’s parallel line (CD). The angle of the α angle locator was adjusted to the measured α value by rotating its rotary knob, and the length of the connecting telescopic rod was adjusted so that the distance between the circle center (B) of the α angle locator and circle center (E) of the β angle locator was equal to d1. The β angle locator was then kept in vertical balance and adjusted to the measured β value by rotating its rotary knob. The puncture needle was subsequently inserted into the guide wire and slowly pushed through skin-muscle tissues to pass through the narrow intervertebral foramen until it entered into the target spot (O) inside the spinal canal. The distance between the circle center (E) of the β angle locator and the puncture needle tip F (the EF distance was presented as d3) was measured. When the total length of the puncture needle subtracted by d3 equaled d2, it indicated that the puncture needle tip had reached the target spot. A mobile C-arm X-ray machine (Mobile X-ray Image System; ARCADIS Orbic/orbic 3D; Siemens AG, Munich, Germany) was used for the second lumbar anteroposterior fluoroscopy and the third lumbar lateral fluoroscopy to confirm the puncture needle tip was at the target spot. The collimator was then removed and the distance on the puncture needle between the puncture point (G) and the point F (presented as d4) was measured. The depth from point G to target spot O was obtained by subtracting d4 from the total length of the puncture needle (Fig. 1).

Table I. General characteristics of patients in the experimental and control group before surgery.

| Characteristics                                      | Experimental group | Control group | P-value |
|------------------------------------------------------|--------------------|---------------|---------|
| Sex, male/female                                     | 20/11              | 19/16         |         |
| Age, years                                           | 37.4839±7.6587     | 39.7143±7.3707| 0.233   |
| Duration of lumbocrural pain, months                 | 13.9839±11.7022    | 14.3143±11.2819| 0.907   |
| Preoperative VAS                                      | 6.5161±0.9957      | 6.6857±0.9632 | 0.485   |
| Preoperative ODI                                      | 65.1935±10.9436    | 65.7714±10.6467| 0.829   |
| Herniated lumbar disc segment (no. of patients)      | L3/4 (2), L4/5 (24), L5/S1 (5) | L4/5 (27), L5/S1 (8) |         |

Data are presented as the mean ± standard deviation. VAS, visual analogue scale; ODI, Oswestry disability index.
Local subcutaneous infiltration anesthesia was performed for the puncture using 2% lidocaine. The puncture needle’s stylet was removed and guide wire was inserted. Subsequently, the puncture needle was withdrawn and a ~1 cm long horizontal incision was made at the puncture point. Expanding sleeves were inserted step-by-step under the guidance of guide wire until the working sleeve was inserted into the correct location. During sleeve insertion, the sleeve length exposed outside of the skin was measured, and the sleeve length inside the body was calculated by subtracting the outside sleeve length from the total sleeve length. When the length of the sleeve in the body equaled the value of $d_4$, the front end of the sleeve had reached the target spot. The mobile C-arm X-ray machine was used for the fourth lumbar anteroposterior fluoroscopy and the fifth lumbar lateral fluoroscopy to confirm the sleeve’s front end was at the target spot. A full endoscope was placed inside the working sleeve and the nerve-compressing lumbar disc herniation tissue was directly removed under the monitoring of a video camera. The nerve root was probed and loosened and bipolar radiofrequency ablation (to decompress the intervertebral disc) and angioplasty were performed.

**Surgical method for the control group.** The surgical method for the control group was conducted according to previous research (11,13,15). The patient was asked to lie in the prostrate position on the operating table, and the position was adjusted to allow for lumbar overflexion so that the waist plane was parallel to the floor. The center line of the lumbar vertebrae and a parallel line passing through the upper margin of lumbar disc were marked under lumbar anteroposterior fluoroscopy using a mobile C-arm X-ray machine. A lateral line through the upper posterior margin of the lower vertebrae...
following the direction of intervertebral tilt under lumbar lateral fluoroscopy was also marked. The intersection of the lateral line and the parallel line passing through the upper margin of the lumbar disc represented the puncture point. The puncture was performed from the upper posterior margin of S1 at an angle between 30‑40˚ for L4/L5 lumbar disc abduction, and between 40‑50˚ for L5/S1 lumbar disc abduction.

Disinfection was frequently performed on the surface of the skin around the surgical area, and an aseptic towel was placed over the skin. Local anesthesia was performed for the puncture point using 2-3 ml lidocaine (1%; v/v). Under lumbar anteroposterior and lateral X‑ray fluoroscopy and following the marked line, the puncture needle was pushed free-hand through skin-muscle tissue and the front edge of the superior articular process to enter into the target spot in the spinal canal. The guide wire was subsequently inserted and the puncture needle was withdrawn. A ~1 cm long horizontal incision was made at the puncture point. The expanding sleeves were inserted step-by-step under the guidance of guide wire and, in case there were any bony obstructions of the articular process, a serrated reamer was inserted to remove some of the bony substance from the lateral margin of the superior articular process. Subsequently, the working sleeve was inserted. During puncturing and sleeve insertion, the location of the puncture needle tip and the sleeve's front end were confirmed using multiple X‑ray fluoroscopies. A full endoscope was placed inside the working sleeve and the nerve-compressing lumbar disc herniation tissue was directly removed under the monitoring of a video camera (Stryker 1288 HD Endoscopic Camera; Stryker, Kalamazoo, MI, USA). The nerve root was then probed and loosened and bipolar radiofrequency ablation decompression and angioplasty of the lumbar disc's annular gap were performed.

Observation method. The number of X-ray fluoroscopies performed during puncturing and sleeve insertion was recorded and the targeted puncture accuracy was observed. The degree of the patient's pain response during sleeve insertion was assessed and categorized into mild, moderate and severe. Mild pain indicated that the patient did not exhibit any reactive body movement to pain, with blood pressure <140 mmHg, respiratory rate <22 min⁻¹ and heart rate <100 min⁻¹. Moderate pain indicated that the patient exhibited slight reactive body movement to pain, with blood pressure <140 mmHg, respiration rate <22 min⁻¹ and heart rate <100 min⁻¹. Severe pain indicated that the patient shouted with both hands fisted, the lumbar muscle was noticeably tense and obvious reactive body movement to pain was exhibited, with blood pressure >140 mmHg, respiration rate >22 min⁻¹ and heart rate >100 min⁻¹. The surgical effect was evaluated according to VAS and ODI scores.

Statistical analysis. Statistical analysis was performed using SPSS v.21.0 (IBM SPSS, Armonk, NY, USA). Results were statistically analyzed using the Student's t-tests Data are presented as the mean ± standard deviation). P<0.01 was considered to indicate a statistically significant difference.
Results

**PTELD using a lumbar disc herniation target collimator decreases the number of X-ray fluoroscopies required and increases the accuracy of initial puncture.** The number of X-ray fluoroscopies performed in the experimental group (5.4516±0.8500) was significantly lower than that of the control group (33.5714±8.7356; P<0.01; Table II). As for puncture accuracy, the experimental group had 27 successful cases (87.1%) in the first attempt and 4 successful cases (12.9%) in the second attempt. The control group had 3 successful cases (8.6%) in the first attempt, 2 successful cases (5.7%) in the second attempt, 6 successful cases (17.1%) in the third attempt, 7 successful cases (20.0%) in the fourth attempt, 7 successful cases (20.0%) in the fifth attempt, 2 successful cases (5.7%) in the sixth attempt, 2 successful cases (5.7%) in the eighth attempt, 1 successful case (2.9%) in the ninth attempt and 5 successful cases (14.3%) in the tenth attempt or more. The puncture accuracy of the experimental group was markedly higher than that of the control group (Table III).

**PTELD using a lumbar disc herniation target collimator decreases pain experienced by patients.** As for patient’s pain response during sleeve insertion under local anesthesia, the experimental group had 25 mild cases (80.6%), 5 moderate cases (16.1%) and 1 severe case (3.2%). The control group had 5 mild cases (14.3%), 19 moderate cases (54.3%) and 11 severe cases (31.4%). The overall pain response of the experimental group was significantly milder than that of the control group (P<0.01; Fig. 7).

A total of 5 patients in the control group experienced lower limb radiating pain during puncturing and seven cases experienced buttock pain. The patients informed the surgeon when they experienced pain and puncturing was stopped immediately. The puncture needle was withdrawn and re-punctured following adjustment of the needle angle. No symptoms of nerve root damage were observed. One case in the control group exhibited repetitive hyperpyrexia on the second day after the surgery and this lasted for 1 week. Examination results of blood procalcitonin for this patient was 7.51 ng/ml (the normal range is >0.05 ng/ml). The patient subsequently exhibited secondary pleural effusion and ascites, jaundice and impaired liver function. Treatment using common antibiotics was ineffective, and lumber MRI performed 1 week after surgery demonstrated that infection foci were present in the surgical segment of the lumbar vertebrae and the spinal canal. Through multidisciplinary consultation and discussion, the patient was diagnosed with bloodstream infection, which was suspected to be caused by the large deviation of free-hand puncture that resulted in the puncture needle entering the patient’s intestinal canal and being withdrawn and reused for puncture. Thus intestinal bacteria was carried into the lumbar vertebra, resulting in severe infection. Fortunately, the patient's condition was effectively controlled through the administration of the antibiotic imipenem cilastin sodium (0.5 g once every 6 h for 2 weeks; Merck Sharp & Dohme Corp., Elkton, VA, USA) via an intravenous drip. Both groups experienced no nerve injury, major blood vessel damage or dural sac tearing complications.

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**Table II. Number of intraoperative X‑ray fluoroscopies performed in the experimental and control groups.**

| X‑ray fluoroscopy type | Experimental group | Control group | P‑value |
|------------------------|--------------------|---------------|---------|
| Target puncture        | 3.2581±0.6816      | 14.2857±7.1190| <0.01   |
| Sleeve insertion       | 2.1935±0.6011      | 19.2857±4.9620| <0.01   |
| Total                  | 5.4516±0.8500      | 33.5714±8.7356| <0.01   |

Data are presented as the mean ± standard deviation.

**Table III. Number of targeted puncture attempts required in the experimental (n=31) and control (n=35) groups.**

| No. of puncture attempts | Group          |
|--------------------------|---------------|
|                          | Experimental  | Control       |
| 1                        | 27            | 3             |
| 2                        | 4             | 2             |
| 3                        | 0             | 6             |
| 4                        | 0             | 7             |
| 5                        | 0             | 7             |
| 6                        | 0             | 2             |
| 8                        | 0             | 2             |
| 9                        | 0             | 1             |
| ≥10                      | 0             | 5             |

Figure 7. Degree of pain response exhibited during sleeve insertion in the experimental and control groups. *P<0.01 vs. the control group*.
Postoperative follow-up was conducted for 9-15 months, with a mean of 12.6 months. VAS and ODI scores of the two groups were not significantly different (P>0.01; Table IV).

Discussion

Lumbar intervertebral foramina are narrow and usually obstructed by the articular process and the transverse process at the back. Important tissues pass through the lumbar intervertebral foramina, including blood vessels, the intestinal canal and nerve roots. The majority of intervertebral disc herniation tissues are located inside the spinal canal and intervertebral foramina and often exhibit downward displacement. Upward displacements are only observed in rare cases. When performing PTELD free-hand, the puncture needle passes through the narrow intervertebral foramen and enters the spinal canal to reach the point of intervertebral disc herniation. Surgeons must rely on their hand's sense of touch and practical experience and, therefore, in the majority of cases, the puncture cannot be successfully conducted on the first attempt. X-ray fluoroscopy is required to be performed repeatedly in order to confirm the location of the puncture needle tip. In the case of an undesired puncture needle tip location, it is necessary for the needle angle to be adjusted or for the puncture point location to be altered. Repeated X-ray fluoroscopies result in increased X-ray exposure and once X-ray exposure exceeds the occupational exposure limit (16) it will cause radioactive damage to the human body.

In the experimental group of the present study, the depth from the puncture point to the target spot had been measured in advance and the length of the sleeve's in-skin part and its location were estimated by measuring the length of the exposed part of the sleeve outside of the skin during sleeve insertion. This meant that repetitive X-ray fluoroscopy was not necessary to confirm the location of the sleeve's front end. In this way, X-ray exposure dose may be effectively reduced and radioactive damage to the surgeon and patient may be avoided. During free-hand targeted puncture, involuntarily shaking of the surgeon's hands may cause deviation of the puncture needle from the target spot. A large deviation may injure important blood vessels, nerves, the intestinal tract and other tissues, and even cause severe adverse outcomes. In the control group of the present study, the puncture deviation was relatively large in 12 cases, in which the puncture needle touched nerve roots and induced lower limb and buttock pain. However, the surgeon communicated with the patients throughout the procedure and the puncture needles were withdrawn as soon as the patient experienced any pain. This meant that accidental puncture injury to the nerve roots was limited. In 1 case of the control group, the patient had a relatively smaller body shape compared with the other patients and free-hand puncture had a large deviation. The puncture needle entered the intestinal canal and, after withdrawal and re-puncturing, carried intestinal bacteria into the lumbar vertebra after the needle angle had been adjusted. This resulted in a severe bloodstream infection. Fortunately, the infection was effectively controlled following antibiotic treatment. In the experimental group, a collimator was used to guide the puncture needle during the procedure. Once the puncture angle and depth were preset, the puncture needle was slowly inserted along the guide tube without shaking, thus effectively avoiding injury to important tissues and reducing the surgical risk. Common complications of PTELD are nerve injury and cerebrospinal fluid leak (1-3). The incidences of hematoma and infection are relatively low, at 0.97 (17) and 0.12% (18), respectively. It is evident that large puncture deviation may injure the blood vessels and cause hematoma (17); however, whether nerve injury, cerebrospinal fluid leak and infection are associated with puncture injury has not been reported.

The intervertebral disc herniation target collimator developed in the present study performs 3D target collimation based on the orthogonal trigonometric function relationship between one distance and two angles. The collimator has a simple structure and is easy to operate. Once the distance from the target spot of lumbar disc herniation tissue to the spot's vertical projection point on the lumbar plane, and the two puncture angles between the puncture path line and the sagittal plane and cross-section plane are determined, the puncture depth may be calculated by the orthogonal trigonometric function relationship. The calculation method is scientific and has high puncture accuracy. Contrastingly, other intervertebral disc puncture locators (19-24) have poor puncture accuracy and no scientific puncture methodology and only guide the puncture needle into the intervertebral disc. Such methods are only suitable for rough positioning and puncture, and are not able to reach the extremely small locations of intervertebral disc herniation tissue in the spinal canal. The discectomy performed following puncture guidance by such intervertebral disc locators is only able to achieve indirect decompression of nerve roots, and is far from meeting the requirement of high accuracy in targeted puncture of transforminal endoscopic discectomy (25). Furthermore, waist size varies among patients, and the collimator developed in the present study is suitable for each individual patient due to its unique design of a telescopic rod with adjustable length.

Individual patients with lumbar disc herniation suffer from varying degrees of kyphoscoliosis and rotation deformities, lumbar disc herniation tissue location varies from patient to patient.

Table IV. Comparison between postoperative lumbocrural pain VAS and lumbar ODI in the experimental and control groups.

| Measure of pain     | Experimental group          | Control group          | P-value |
|--------------------|----------------------------|------------------------|---------|
| Postoperative VAS  | 1.2581 ± 0.9298            | 1.4571 ± 1.0939        | 0.427   |
| Postoperative ODI (%) | 16.1935 ± 8.4437          | 18.0571 ± 9.1071       | 0.394   |

Data are presented as the mean ± standard deviation. VAS, visual analogue scale; ODI, Oswestry disability index.
patient and lumbar anatomical variation may exist. Therefore, when applying a posterolateral percutaneous transfemoral approach, each patient has a different puncture point location, angle and surgical path, highlighting the importance of a personalized surgical approach. It is necessary for the puncture path and surgical approach to be personally customized prior to surgery, thus selecting the best personalized surgical approach is a surgeon's primary concern. The most effective surgical approach, which may be designed preoperatively based on lumbar MRI or CT images, is required to avoid damage to bone, nerves, blood vessels, the intestinal tract and to muscle tissue.

The targeted puncture methodology designed in the present study meets the requirements of a personalized surgical approach. The puncture path is designed on lumbar MRI or CT cross-sectional images. The punctures performed in the experimental group had large abduction angles of 65-80°. The puncture point was relatively far from the mid-spinal line, at a distance of 12-15 cm, making it possible to effectively avoid bone substance obstruction of the articular process. This meant that a reamer was not required to remove bone substances and the patient experienced minimal pain during sleeve insertion. In comparison, in order to avoid large puncture deviation that may injure the vessels, nerves, intestinal canal and other tissues, free-hand puncture performed in the control group had smaller abduction angles of approximately 30-50°. The puncture point was relatively close to the mid-spinal line at a distance of 9-12 cm, which meant encounters with bony obstructions of the superior articular process were possible. Thus, it was necessary for some bone substances to be removed to enlarge the intervertebral foramen so that the sleeve was able to enter into the spinal canal. The patients in the control group exhibited the highest number of severe pain responses during sleeve insertion. Patients in the experimental group exhibited milder pain responses during sleeve insertion and were overall more relaxed throughout the surgical process compared with the control group.

Certain errors may be made when measuring the distance between the target spot and its vertical projection on the lumbar plane. The reason why the present study chose to perform the measurement on the lumbar overflexion X-ray radiograph is because the patient’s prostrate position on the operating table is similar to lumbar overflexion. The vertical projection of the target spot on the lumbar plane was within the 1-2 cm radius of the spinous process under the majority of circumstances, thus it was not possible to use CT images and MRI to measure the distance between the target spot and its vertical projection on the skin. As the skin at the spinous process of the mid-spinal line is sunken while the erector spinae uplifts, the measured distance is smaller than the distance on the lumbar plane. If the patient is not in a suitable position when taking the lumbar overflexion X-ray radiograph prior to surgery, it may increase the measurement error, which would subsequently need to be corrected. If the puncture needle tip is found to be deviated from the target spot by X-ray fluoroscopy, it may be fixed by simply line-adjusting the β angle locator of the collimator. As the PTELD technique has a long and steep learning curve (26-29) and high technical difficulty, it is not easy to master (30,31). Inexperienced surgeons are not necessarily able to accurately puncture the needle onto the target spot in the spinal canal even after repeated adjustments of the puncture needle angle and location, thus they are unable to effectively remove nerve-compressing intervertebral disc herniation tissues. Therefore, it is only possible to perform indirect nerve root decompression and the surgical effect will reduce due to incomplete nerve decompression. The collimator and the novel methodology of guided puncture presented in the present study is able to theoretically shorten the learning curve; however, this was not considered in the present study and will be the focus of future research.

The present study has adequately demonstrated that using the novel collimator-guided targeted puncture technique is able to effectively reduce the exposure of the human body to high X-ray doses, as well as limit a patient's pain and the surgical risk. Renowned experts proficient in surgery with steady hands, effective sense of touch and rich practical experience are able to achieve high accuracy and reduce X-ray exposure when performing free-hand percutaneous targeted puncture; however, for surgeons without proficient surgical skills and surgical experience, using the new collimator-guided targeted puncture technique may be more effective.

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