Technical Note

Isocentric Navigation of Percutaneous Endoscopic Transforaminal Discectomy at the L5/S1 Level in Difficult Puncture Cases: A Technical Note

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Background: Accurate puncture during percutaneous transforaminal endoscopic discectomy at the L5/S1 level in cases with high iliac crest and narrow foramen were difficult, even though the difficulties of foraminoplasty could be overcome by advanced instruments like reamers.

Objectives: The report aimed to describe an isocentric navigation technique with a definite pathway in difficult puncture cases at the L5/S1 level.

Study Design: Technical note.

Setting: Difficult punctures were defined as over 10 punctures of the needle before obtaining an ideal puncture location by senior surgeons with experience of over 500 percutaneous endoscopic transforaminal discectomy (PETD) cases.

Methods: A total of 124 punctures were recorded in 11 difficult puncture cases at the L5/S1 level. A definite pathway was created by an isocentric navigation theory, which was based on a surface locator and an arch-guided device. The surface locator was used to rapidly and accurately identify the puncture target with the recognition of the surrounding rods under fluoroscopy. The arch-guided device can ensure that the puncture target always remains at the center of a virtual sphere. We recorded the puncture times, fluoroscopy exposure times, radiation exposure time, operative time, visual analog scale (VAS) score, Japanese Orthopeadic Association (JOA) score, and patient satisfaction.

Results: The average puncture times were significantly reduced to 1.27 with the arch-guided device compared with conventional puncture methods ($P < 0.05$). The average operative time was 90.09 ± 11.00 minutes and the fluoroscopy times were 53.36 ± 5.85. The radiation exposure time was 50.91 ± 5.20 seconds. VAS score of leg and back pain, as well as JOA score, were all significantly improved after surgery ($P < 0.05$). The excellent and good rate of satisfaction was 90.91%. No major complications, including cerebral fluid leakage, surgical infection, and postoperative nerve root injury, were recorded in this small sample.

Limitations: This was a small-sample study with a short follow-up.

Conclusions: The novel isocentric navigation technique with a definite pathway is practical and effective in reducing puncture times among difficult puncture cases at the L5/S1 level, which may contribute to the capacity of PETD at the L5/S1 level.

Key words: Percutaneous endoscopic transforaminal discectomy, difficult punctures, radiation exposure, definite pathway, high crest

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Lumbar disc herniation (LDH) is considered to be a common cause of lower back and leg pain, and its incidence is increasing due to the modern sedentary lifestyle (1). Development of instrumentation such as a working cannula, endoscope, laser, trephine drill, and radiofrequency probe has popularized percutaneous endoscopic lumbar discectomy (PELD) as a minimally invasive spine surgery for symptomatic LDH (2,3). PELD via the transforaminal approach (PETD, percutaneous endoscopic transforaminal discectomy) has been widely applied in various conditions, such as removal of migrated herniations, foraminal/extraforaminal herniations, and recurrent herniations (4-6). PELD via the interlaminar approach (PEID, percutaneous endoscopic interlaminar discectomy) is another popular technique, but it requires general anesthesia and partial removal of the flavum ligament, and motion of the dural sac medially (7). As a result, there is a risk of injury to the dura and the incidence of dural damage is approximately 1.75% according to a previous report (8). On the other hand, foraminotomy with instruments like reamers have enabled PETD in most LDH at L5/S1 (9,10). Additionally, the risks of dural damage and subsequent cerebral fluid leak in PETD are reduced due to the maintenance of the integrity of the flavum ligament (11). PETD has been well validated with non-inferior efficacy to microdiscectomy. Furthermore, PETD involves a small incision, local anesthesia, no muscular traction, low risk of iatrogenic neurologic damage, direct approach to the extruded disc fragment, rapid recovery, minimal risk of infections, short operative time, and low postoperative costs (12,13).

Nevertheless, at the L5/S1 level, PETD requires a craniocaudal direction of the working channel, which may be challenge for many surgeons with initial punctures (14). Accurate punctures in the transforaminal route heavily rely on surgeons' experience, but many L5/S1 cases with a high iliac crest, narrow foramen, and enlarged transverse process are confronted in clinical practice regardless of experience. In such cases, punctures in the conventional trial-and-error manner induced repeated fluoroscopy and increased radiation exposure, which is a great concern in current operating rooms (15,16). To minimize the radiation hazards during the puncture procedure of PETD, it is very important to accurately identify the puncture target and to plan a feasible trajectory, as well as to keep the planned puncture trajectory in tract (17). Thus, we will describe an isocentric navigation technique with a surface locator to plan a feasible trajectory and an arch-guided device to keep a definite pathway for these difficult puncture cases at the L5/S1 level in PETD.

Methods

General Information

This study was approved by our local institutional review board, and consent forms were obtained from all included patients. From November 2014 to May 2015, PETD cases at the L5/S1 level with difficult punctures in a conventional trial-and-error manner were included. Difficult punctures were defined as more than 10 cannula punctures before obtaining an ideal puncture location by senior surgeons with experience of over 500 PETD cases. All included patients underwent all-round assessment, including clinical symptoms and signs, as well as radiographic assessment such as x-ray, magnetic resonance imaging (MRI), or/and computed tomography (CT).

Surgical Procedures

Patients were placed in the prone position on the radiolucent table. The surgical level was roughly estimated by palpating the iliac crest and patient's back. Surface locators were then attached onto the dorsal and lateral skin of the patients by adhesive tape (Fig. 1A). Concisely, the surface locator was used to rapidly and accurately identify the puncture target with the recognition of the surrounding rods under fluoroscopy. G-arm fluoroscopy (Biplanar 500e, Swemac imaging™, Sweden) was used to conduct the anteroposterior and lateral fluoroscopy. Considering the anatomic relationship between surface locator and anatomic structures, we could rapidly identify the vertebral arches of the surgical level, the superior edge of the superior articular process of the inferior vertebrae, the midline, the transverse process, and the iliac crest on anteroposterior fluoroscopic images. We could also identify the foramen and the isthmus on lateral fluoroscopic images. The posterior projection of the planned trajectory was determined by the puncture target, the superior edge of superior articular process of the inferior vertebrae, the transverse process, and the iliac crest (Fig. 1B). The lateral projection of the planned trajectory was determined by the puncture target and the superior edge of the superior articular process of the inferior vertebrae (Fig. 1C). We marked the anatomic details on the skin and drew the planned trajectory (Fig. 1D). The intersection point of the posterior and lateral projection of the planned trajectory on the skin was regarded as the entry point. In addition, we measured the distance from the entry point to the midline (12 – 16 cm) to re-confirm the selection of the entry point (Fig. 1E). Afterwards, we conducted the routine disinfection of the surgical area (Fig. 1F) and administrated the local anesthesia.

Initially, patients received conventional punctures in a trial-and-error manner relying on the surgeons' experience. However, after 10 failed punctures, we decided to use an arch-guided device to assist with the punctures to shorten the operative time and reduce radiation exposure. The isocentric navigation theory of the arch-guided device is that the puncture target always remains at the center of a virtual sphere that created by a virtual 90-degree arc. In this way, when the needle guider reaches the skin entry point, the needle can be inserted directly into the puncture target (Fig. 2). The arch-guided unit of the arch-guided device mainly consists of a fixed block, a slider, a 1/4 circular arch, a guider rod, a needle guider, and 2 beam generators. After autoclave sterilization of arch-guided unit (except beam generators for plasma sterilization), we installed the arch-guided unit of arch-guided device (Fig. 3). Then we inserted the arch into the slider and guide rod to the arch, and fixed the needle guider to the guider rod. For the sake of safety, we re-checked the intersections of the 2 beams and the needle tip before every operation.

After that, we moved the arch-guided device above the surgical area of the patient. We regulated the position of the arch until the vertical beam targeted the posterior marker (posterior projection of the puncture target) and the horizontal beam targeted the lateral marker (lateral projection of the puncture target) (Fig. 4A). We could freely rotate the arch along with the vertical axis and regulate the guide rod on the tract of the arch until the guide rod reached the

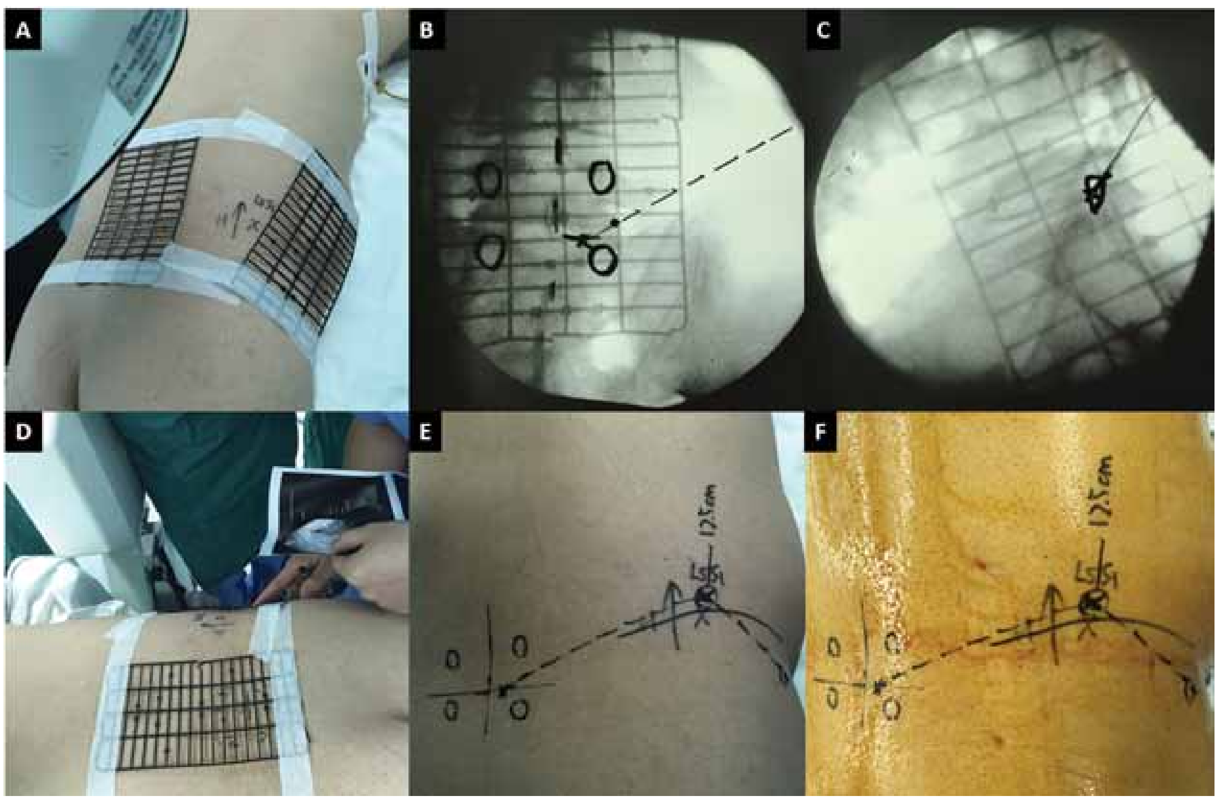

Fig. 1. *Accurate preoperative location for percutaneous transforaminal endoscopic discectomy. A: surface locators were attached to the back and lateral skin; B: identification of anatomic details under anteroposterior fluoroscopy; C: identification of anatomic details under lateral fluoroscopy; D: mark anatomic details on the skin; E: planned trajectory on the skin; F: disinfection after planned trajectory.*

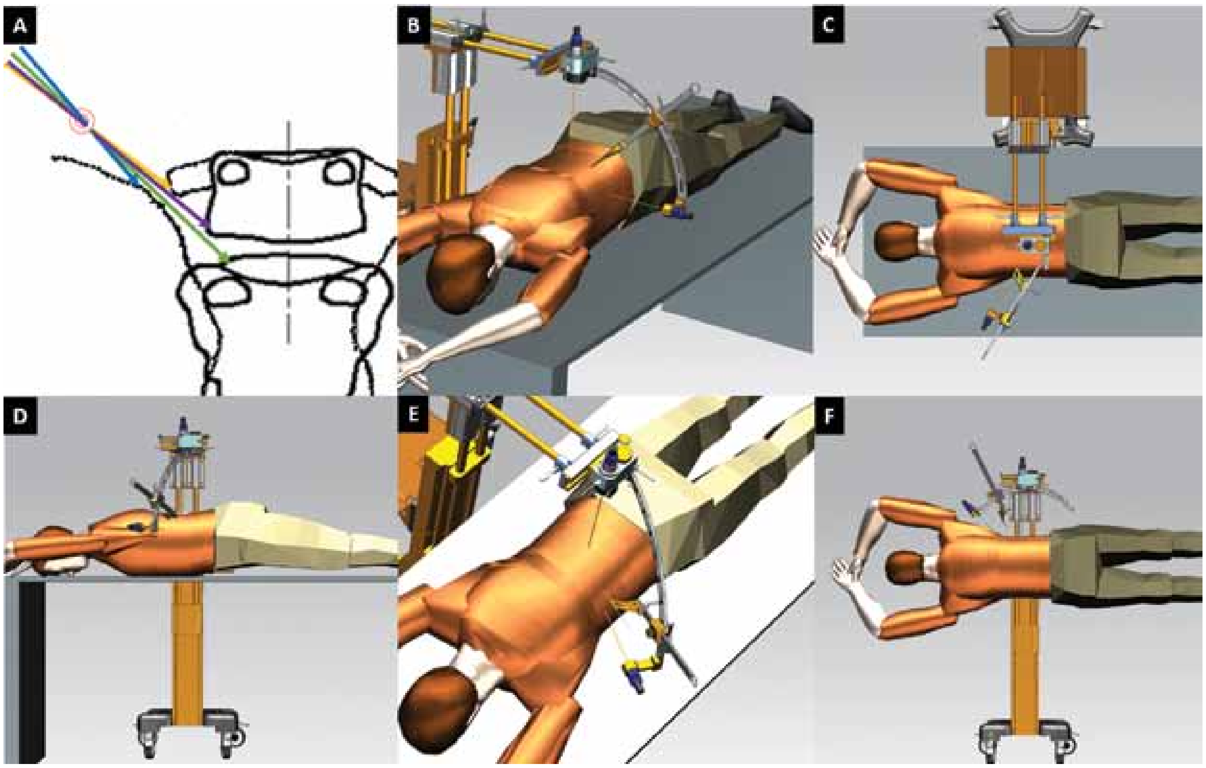

Fig. 2. *Schematic for a definite pathway induced by arch-guided device. A: difficult punctures at L5/S1 level; B: puncture target remains at the center of a virtual circle determined by 2 beams and parallel with the 1/4 circular arch; C: the virtual arch can be rotated along with the vertical axis to create a virtual sphere; D: the guide rod can be slid on the tract of the arch; E: the guide rod can be extended to enable the needle guider to reach the entry point; F: arch-guided device can also be applied in lateral position if necessary.*

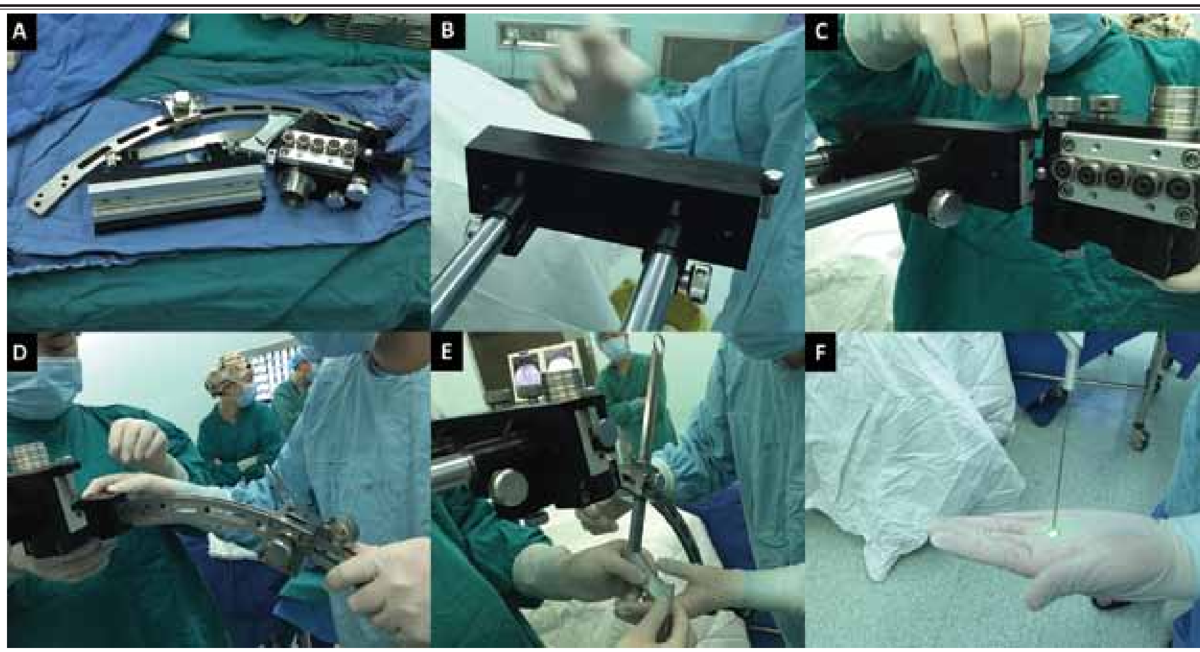

Fig. 3. *Installation of arch-guided unit of arch-guided device. A: disinfection of arch-guided part; B: installation of fixed block; C: installation of slider; D: installation of arch; E: installation of guide rod and needle guider; F: confirmation of the intersections of 2 beams and the needle tip prior to operation.*

entry point (Fig. 4B-D). Then, we could insert the needle through the needle guider directly to the puncture target, followed by the guidewire (Fig. 4E-F). We moved the arch-guided device without changing the vertical distance of the arch, and then conducted fluoroscopy to confirm the location of the guidewire. If the initial position of the guidewire was unsatisfactory, we could quickly move back the arch-guided device with the vertical beam onto the posterior marker. At this very moment, the puncture target remained at the center of the virtual circle determined by the 2 beams. Thus, we could quickly conduct another puncture and confirm the location with the assistance of fluoroscopy. It would be also satisfactory, if the initial puncture by the arch-guided device did not directly access to the herniated disc location. As long as the puncture tip was close to the medial pedicular line, we could conduct a conventional free-hand redirection of the initial needle trajectory to target to the herniation. The procedures were similar to conventional methods (18,19), and trephine or reamers were applied for foraminotomy if necessary.

Clinical Assessment

We measured visual analog scale (VAS) of leg and back pain, as well as Japanese Orthopeadic Association score (JOA) preoperatively and postoperatively at one-year follow-up. MacNab score (excellent, good, fair, poor) was used to evaluate patients' satisfaction. We recorded the preoperative marking time, operative time, fluoroscopic times (frequency), radiation exposure time, and hospital stay. We also measured the anatomic parameters of difficult puncture cases to demonstrate the potential differences with normal puncture cases. Disc height (L5/S1), foramen (foraminal cross sectional) area (L5/S1), iliac crest height, and iliolumbar angle as well as distance between the iliac crest and transverse

Fig. 4. *Application procedure of arch-guided device. A: vertical beam targeting on the posterior marker and horizontal beam targeting on the lateral marker; B: rotate the arch along with the vertical axis; C: regulate the guide rod on the tract of the arch; D: extend the guide rod to reach the entry point; E: insert the needle; F: insert the K wire and pull out the needle.*

process were measured. The iliac height was defined as the vertical distance from the S1 plate to the highest iliac bone. The iliolumbar angle was defined as the angle between a line from the superior and medial point of the S1 pedicle to the highest iliac point and a horizontal line (20).

Statistical Analysis

Statistic software SPSS17.0 (SPSS, Inc., Chicago, IL, United States) was adopted to conduct the statistical analysis. Measurement data were demonstrated as mean ± standard deviation (SD). Student t-test was used to compare the difference of continuous variables. Statistical significance was defined when the probability value was less than 0.05.

Results

A total of 124 punctures were recorded in 11 difficult puncture cases at the L5/S1 level (Fig. 5). The average age was 59.82 ± 9.43 years old, and the body mass index was 22.91 ± 0.69 kg/m^2. The average follow-up was 14.36 ± 1.96 months. The radiographic parameters of difficult puncture cases are summarized in Table 1. As demonstrated in Table 2, the average puncture times were significantly reduced to 1.27 with the arch-guided device compared with conventional puncture methods ($P < 0.05$). The average operative time was 90.09 ± 11.00 minutes and the fluoroscopic times were 53.36 ± 5.85. The radiation exposure was 50.91 ± 5.20 seconds and the hospital stay was 2.27 ± 0.79 days. VAS score of leg and back pain, as well as JOA score were all significantly improved after surgery ($P < 0.05$). The excellent

Fig. 5. *Difficult puncture case at L5/S1 level. A: lateral magnetic resonance imaging of a typical L5/S1 lumbar disc herniation case; B: anteroposterior magnetic resonance imaging demonstrated a paracentral lumbar disc herniation; C: computed tomography of L5/S1 lumbar disc herniation; D: lateral x-ray showed limited foraminal area; E: anteroposterior fluoroscopy demonstrated successful puncture; F: lateral fluoroscopy demonstrated successful puncture.*

Table 1. *Basic characteristics of included difficult puncture cases.*

Variables	Results
Gender (male:female)	10:1
Age (year)	59.82 ± 9.43
Conservative time (months)	9.36 ± 2.25
Body mass index (kg/m^2)	22.91 ± 0.69
Follow-up (months)	14.36 ± 1.96
Lumbar disc herniation (central:paracentral)	2:9
Disc height (cm)	0.74 ± 0.20
Foramen area (cm^2)	0.50 ± 0.13
Iliac crest height (cm)	4.85 ± 0.69
Iliolumbar angle (°)	41.45 ± 4.32
Distance between iliac crest and transverse process (cm)	0.35 ± 0.31

Table 2. *Clinical outcomes of included difficult puncture cases.*

Variables	Results
Conventional puncture times	10.00 ± 0.00
Puncture times with arch-guided device*	1.27 ± 0.47
Preoperative location time (min)	4.28 ± 0.57
Operative time (min)	90.09 ± 11.00
Fluoroscopic times (frequency)	53.36 ± 5.85
Radiation exposure (s)	50.91 ± 5.20
Hospital stay (days)	2.27 ± 0.79
Anteroposterior voltage (kV)	87.27 ± 3.41
Lateral voltage (kV)	106.27 ± 4.67
Anteroposterior current (mA)	3.29 ± 0.41
Lateral current (mA)	4.05 ± 0.28
MacNab satisfaction (excellent:good:fair:poor)	7:4:0:0
Preoperative back VAS	5.91 ± 0.70
Postoperative back VAS*	1.36 ± 0.50
Preoperative leg VAS	6.73 ± 1.10
Postoperative leg VAS*	1.55 ± 0.82
Preoperative JOA	17.64 ± 1.85
Postoperative JOA*	23.09 ± 1.30

and good rate of satisfaction was 90.91% (one case reported fair). No symptomatic residual disc herniations were observed after the operation, and no major complications including cerebral spinal fluid leakage, surgical infection, and postoperative nerve root injury were encountered. One recurrent disc herniation was observed during the follow-up, and another PETD was successfully conducted. All included patients are still in long-term follow-up.

Discussion

Accurate puncture is a key step in PETD, and an ideal trajectory is determined by an accurate location of the puncture target and a planned entry point. The current report introduced an isocentric navigation technique with a definite trajectory for PETD in difficult puncture cases at the L5/S1 level, which significantly reduced the puncture times and radiation exposure. This study confirmed the capacity of a definite pathway in difficult puncture cases, and further indicated the feasibility of PETD at the L5/S1 level.

PELD, a percutaneous technique with the lighting system, irrigation system, and operation system integrated in one tube, is also called full-endoscopic technique discectomy (21). In current clinical practice, the decision of PETD or PEID for L5/S1 disc herniations mainly depends on the surgeon's preference and surgical experience. PETD was preferred for shoulder type, centrally located, and recurrent LDH, while PEID was preferred for axillary type and migrated discs, especially those of a high grade (20,22). In our cases, we could have transferred from PETD to PEID after dozens of unsuccessful punctures, but it would have changed the local anesthesia to general anesthesia. Thus, we insisted on PETD because partial anatomic obstruction is no longer a problem with the development of reamers, trephine, and other drilling instruments However, the initial punctures anchoring onto the puncture target still remained a problem due to narrow foramen, enlarged transverse process, and high crest at L5/S1. The conventional free-hand regulation of punctures might have a chance to obtain an ideal puncture, but it relied on a trial-and-error manner and repeated fluoroscopy, which was correlated with more radiation exposure. Thus, the definite pathway was important for the initial punctures.

Initial successful puncture is key to establish a working channel through the foramen to the appropriate surgical target, which might increase the chance for a full-endoscopic discectomy (23). A single center with 12-years' experience of 10,228 cases has confirmed that non-ideal working channel position played an important role in unsuccessful PELD cases (14). However, the percutaneous approach poses great challenges to surgeons, because the surgeons need to conduct the puncture based on their experience, which leads to a steep learning curve (24,25). Surgeons may need dozens of punctures at the L5/S1 level in order to obtain an ideal position for the following guidewire. The

L5/S1 foramen is obstructed by the iliac crest and the transverse process, and it is very difficult to maintain the same plane with the L5/S1 disc space while avoiding the ilium during cannula puncture (19). Only when a successful puncture at the L5/S1 level is achieved, can the following trephine drill and working channel be placed into an ideal position (26). Our study confirmed that accurate preoperative identification of a puncture target, personal entry point selection, and performing the puncture by utilizing the planned trajectory were 3 important factors in obtaining a successful cannula puncture and establishing a working channel.

Accurate preoperative identification of the cannula puncture site is an essential step in minimally invasive spine surgery, which enhances the predictability of the surgical result, in accordance with demands for precision, efficiency, and minimal tissue damage. The conventional preoperative identification of the puncture target includes palpation of the spinous processes and iliac crests (27,28) and using surgical instruments (clips, Kirschner wires, or spinal needles). The palpation method is objective, but may lead to inaccuracy by not considering a combination of many factors, such as a patient's size, scapular shadows (29), and decreased bone density (i.e., osteoporosis) seen on standard radiographs or fluoroscopy. The Kirschner wire method is more frequently used in clinical practice. However, this method may require repeated adjustments of the Kirschner wire and the C-arm fluoroscope to ensure the location of the bone landmarks. As a result, this trial-and-error manner may increase the radiation exposure to both the medical staff and the patients (30). As for our surface locator, it was very simple and straightforward to localize the puncture target, which usually needed only one fluoroscopy frequency to identify the projection of all related anatomic details by the surrounding markers. Considering the projections of the puncture target and anatomic markers surrounding the potential trajectories, we could rapidly determine the posterior projection of the puncture trajectory on the anteroposterior fluoroscopic images, and the lateral projection of the puncture trajectory on the lateral fluoroscopic images. As depicted in Fig. 2, the intersection point of the posterior and lateral projections of the planned trajectory on the skin was regarded as the entry point. This preoperative location method is rapid and accurate, which helps minimize radiation exposure. In addition, we are currently investigating software to calculate the optimal trajectory in a three-dimensional manner (31).

Navigation technology in minimally invasive spine surgery is a large trend in current practice, and various types of computer-assisted spine surgery (i.e., CT-based, C-arm and the Iso-C 3D C-arm) are increasingly applied around the world (32). However, these navigation techniques are expensive and cumbersome, and there are no known studies reporting their application in PELD. Nevertheless, we must admit that the transforaminal route of PETD may require a practical guide tool to facilitate punctures, especially at L5/S1, where the transforaminal window becomes progressively smaller as the facet joint overlaps the disc space (20). The unique anatomic characteristics of the L5/S1 segment are a large facet joint, narrow foramen, and small disc height. In some cases, a high iliac crest conceals the L5/S1 foramen, which narrows the suprailiac access to the foramen. As we measured in the study, the disc height (L5/S1) and foramen area (L5/S1) were all smaller than normal cases, and the iliac crest height and iliolumbar angle were bigger (20,33). These anatomical obstacles contribute to a difficult puncture case, because it makes the puncture trajectory into a "single-log bridge." Iprenburg et al (34) quantified the radiation exposure of PETD at L5-S1 at 54.6 seconds, but they included many cases without a high iliac crest and narrow foramen. Considering that the cumulative radiation exposure (50.91 ± 5.20 seconds) in our study already included failed conventional punctures, we may assume that the radiation exposure has been minimized with isocentric navigation. The intent of our arch-guided device is to keep the puncture on the tract of this "single-log bridge," and thus significantly reduce puncture times and radiation exposure. It is worth mentioning that our arch-guided device also has the potential to be widely applied in intervertebral disc ablation, abscess drainage, and screw insertions.

Several issues should be noted when interpreting this technical note. Firstly, this was a small-sample study with a very short follow-up. A prospective controlled study with a large number of participants and longer follow-up would be more persuasive to validate this technique. However, since the radiographic definition of difficult puncture cases was not available in practice, we could not conduct a controlled study to compare the novel technique with a definite pathway versus the conventional puncture manner in difficult puncture cases. Secondly, we have not compare PETD with this technique versus PEID at the L5/S1 level yet. We are currently endeavoring to clarify this issue and in another study define radiographic difficult punctures.

Additionally, we were also investigating the benefits of this isocentric navigation technique for naive surgeons conducting PETD. Finally, the accurate location of puncture target projections on the skin was very important. When marking the posterior projection of the puncture target, we recommend referring to the lateral projection of the puncture target with the right-angle edge of the surface locator, since there was a normal sagittal slope at the L5/S1 intervertebral space. One could also draw a line parallel to the disc space in the posterior projection and the lateral projection to correct and reduce parallax error.

Conclusion

The novel isocentric navigation technique with a definite pathway is practical and effective in reducing annular puncture times among difficult puncture cases at the L5/S1 level, which might contribute to the use of PETD at the L5/S1 level. Further studies with large samples and a control group should be conducted to investigate the benefits of a definite pathway in these specific cases.

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