Principles of Transforaminal Endoscopic Approach Technique

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1 Introduction

There are many treatment options for degenerative lumbar disc disease, such as medication, physical therapy, epidural injection, percutaneous or endoscopic procedures under local anesthesia, minimally open microscopic surgery under general anesthesia, dynamic stabilization surgery, and instrumented fusion surgery. Various treatment methods for degenerative spine disease could be selected in a stepwise manner (Fig. 1). Among the treatment methods that can ensure successful results, applying the treatment corresponding to lowest step of the stairs is considered a modern concept of minimally invasive treatment.

Lumbar microdiscectomy is still at the forefront of minimally invasive spine surgery (MISS) in the sense that it has the advantages of both minimal invasiveness and a wide range of indications [1, 2]. However, open microdiscectomy usually requires general anesthesia and removal of the posterior element of the spine, and can lead

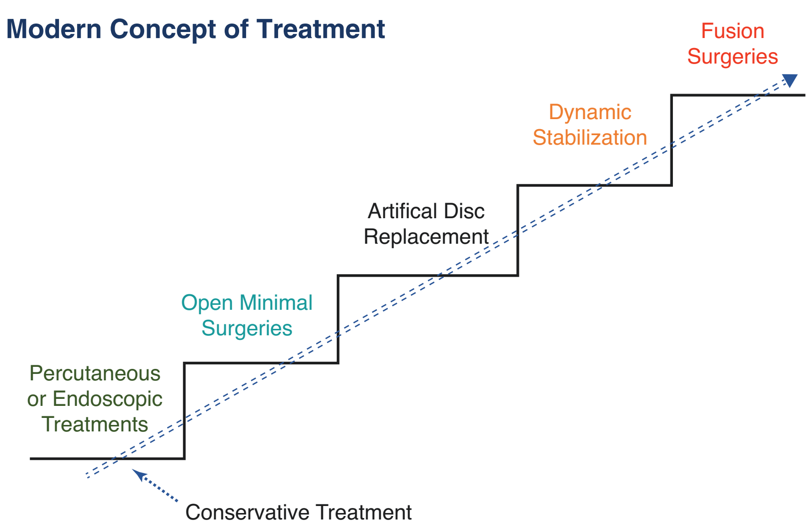

Fig. 1 Modern concept of treatment for degenerative disc disease. The modern concept of minimally invasive treatment is considered to apply the lowest level of treatment methods that can ensure successful results

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to several complications associated with open surgery [3–9]. As a result of efforts to avoid general anesthesia and develop more minimally invasive methods, transforaminal approaches of treatment had been introduced [10–17]. These treatments have been progressively evolved through anatomical studies and advances in equipment and access techniques [18–23]. Subsequently, transforaminal endoscopic lumbar discectomy (TELD) has gradually garnered many clinical reports of favorable outcomes [24–34]. The TELD is one of the most advanced minimally invasive spine surgeries. There are many advantages of TELD [3–5, 10, 21, 24, 25, 31, 33, 34, 47–52, 54]. In summary, TELD can solve only the problem (disc herniation) without any sacrifice (laminectomy, ligament and soft tissue injury, facetectomy, general anesthesia, indwelling catheters, postoperative pain, long duration of hospitalization, and other complications related open surgery) (Fig. 2). In addition to avoiding unnecessary sacrifice, one of the most important concepts and advantages of TELD is that it enables ventral decompression of nerves without retraction through a posterolateral approach.

In the past, the TELD was regarded as minimally invasive but only useful procedures in highly selective cases. However, the evolution of equipment and the development of surgical techniques have allowed the treatment area of TELD to be extended. The development of TELD has progressively advanced the treatment fields from contained disc herniation to uncontained disc herniation, and from indirect decompression to direct decompression with targeted fragmentectomy, from lateral zone disc herniation to the central zone of intracanal disc herniation, and from disc level to beyond the disc level [10–17, 21–28, 35–45]. Improved success rates in these areas have led to the expansion of indications of TELD.

Although randomized control trials (RCTs) are lacking and most studies have not had high level of evidence, many studies including RCTs and meta-analyses have reported that TELD showed similar or more favorable clinical outcomes compared to open lumbar microdiscectomy [5, 24, 25, 31, 33, 46–54]. What is more, most of those studies have highlighted the advantages of TELD in terms of minimal invasiveness, which is an innate characteristic of TELD [5, 24, 25, 31, 33, 47–52, 54].

The rates of recurrence in the case of TELD were reported to be similar to those of open microdiscectomy in most comparative studies, and there was a meta-analysis that reported a lower rate in TELD [31, 46, 47, 50, 55]. However,

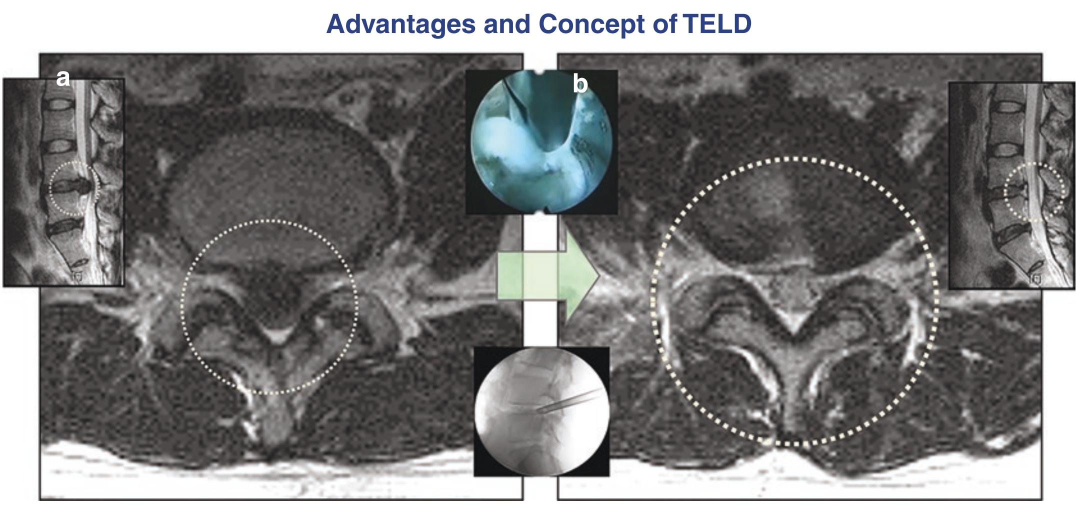


Fig. 2 The concept and advantages of TELD. Preoperative (**a**) and postoperative (**b**) MRI demonstrates that all spinal structures were normalized after TELD. Postoperative MRI showed that there were no unnecessary sacrifices other than removal of the herniated disc. It can be seen that the epidural fats were also well preserved

although the statistical significance was not clear, there were quite a few articles that reported a higher reoperation rate than open lumbar microdiscectomy in patients who underwent TELD [33, 46, 49, 51, 55, 56]. The reason that the reoperation rate was higher for TELD than for open lumbar microdiscectomy was associated with insufficient decompression due to residual herniated discs or early recurrence [46, 56]. The failure rate and reoperation rate of TELD may be related to technical aspects, including surgeon's proficiency [57–60]. On the other hand, it may be related to indications.

There are probably very few spine surgeons who deny that lumbar microdiscectomy is still the gold standard of MISS. The reason may be that lumbar microdiscectomy has a wide range of indications and provides the means for a consistent successful surgical resolution rather than its higher success rate. When it comes to treatment for soft disc herniation, it is expected that TELD will suffice to qualify for a forefront position in the field of MISS. To achieve that, high-quality clinical studies to prove that TELD is a treatment based on evidence-based medicine, expansion and establishment of indications, and efforts to achieve a constant and high success rate are required. The establishment and expansion of indications is related to the identification of prognostic factors and technical capability. Practically, it would be closely related to the accessible range and limitations of the surgeon's endoscopic forceps. The improvement and consistency of the success rate of TELD depends on the appropriate patient selection and the technical aspects to approach the target closely.

In this chapter, the author describes indications and prognostic factors, methods to increase the accessible range of endoscopic forceps, appropriate utilization of equipment characteristics, and approach techniques to reach the target as closely as possible. For standardization of terms, this chapter mainly used the nomenclature and classification of lumbar disc pathology recommended by the North American Spine Society, American Society of Spine Radiology, and American Society of Neuroradiology [61, 62]. Endoscopic treatments for foraminal stenosis and foraminal disc herniation are partially transforaminal procedures. In this chapter, effective treatment methods of transforaminal endoscopic lumbar discectomy for intracanal lumbar disc herniations, which are the main areas of transforaminal endoscopic treatment, are described with an emphasis on approach techniques.

2 Indications

Increasing the success rate of TELD requires knowledge of the indications as well as the implementation of advanced and skilled techniques. Briefly, all symptomatic soft disc herniations within the accessible range of the surgeon's endoscopic forceps are indications of TELD. However, in order to increase patient satisfaction and success rate by selecting appropriate patients, it is necessary to know in detail the clinical, radiological, and technical aspects included in this indication. Knowledge of clinical and radiological factors related to prognosis and understanding of the reachable range and limitations of endoscopic approaches are very helpful in achieving successful outcomes and improving the capacity of surgeons.

2.1 Clinical Considerations

In general, the clinical indications for TELD are intractable back pain and persistent radiating lower extremity pain despite conservative treatment such as medication, physical therapy, and epidural injection.

Published articles related to clinical prognostic factors of TELD suggested that duration of symptoms [32, 63–65], positive Straight Leg Raising (SLR) test [63], age [32, 34, 58, 59, 64, 66, 67], and body mass index (BMI) [59, 66] were statistically related to success rate and recurrence rate. There were also reports that patients with diabetes, smoking, and intense physical labor were associated with surgical outcomes and relapses [58, 68].

Regarding age, many studies have reported that the younger the patient, the more favorable the outcomes [32, 34, 58, 59, 64, 66, 67]. In one nationwide cohort study involving many cases (n = 15,817), percutaneous endoscopic lumbar discectomy for older patients (≥57 years) had a higher reoperation risk during the postoperative 3.4 years than open discectomy [67]. However, it should not be overlooked that many patients at an old age were able to avoid incisional surgery under general anesthesia through endoscopic procedures. TELD can be regarded as belonging to the category of surgery in a broad sense, but it would be a small procedure with a minimal wound less than 1 cm performed under local anesthesia. Some articles reported no significant association between age and clinical outcomes or relapses after TELD [68–70]. Although it is necessary to be careful about postoperative management in older age groups, age and gender do not seem to be factors to be seriously considered in selecting an appropriate patient. One consideration in the different application of treatment between men and women in the field of TELD is that women may be better indications than men at the L5-S1 level, since men tend to have more limitations in the transforaminal endoscopic approach due to their different pelvic structures.

Studies of prognostic factors related to symptom duration reported that patients with shorter duration of symptoms before TELD had better outcomes [32, 63–65].

In selecting a patient, it is worth considering the severity of the symptoms before the TELD. Usually, patient satisfaction is related to differences in visual analogue scale (VAS) pain scores before and after treatment. Therefore, the milder the symptoms before surgery, the less likely the patient's satisfaction after treatment would be. Even though the surgeon stands on early stage of learning curve, it is recommended to select patients with severe herniated disc with a high VAS pain score rather than a low VAS score with mild symptoms.

The positive SLR test is helpful in predicting the severity of disc herniation and can also serve as a predictor of favorable outcome of TELD treatment [63, 71].

Muscle weakness or sensory deficits are not considered contraindications as long as these neurological deficits result from a soft disc herniation. And if sufficient decompression is expected to be achieved with TELD, applying TELD would be a better treatment option than choosing other surgeries that involve nerve retraction that could aggravate the neurological deficit.

It is necessary to carefully examine the possibility that the main cause of the symptoms and signs was not caused by a disc herniation, but by other accompanying spinal diseases. The cause of sudden severe symptoms with straight leg raising (SLR) test positive at <30° must have been due to a herniated disc, even with accompanying stenosis. However, the long-standing symptoms with claudication may have been mainly caused by concurrent stenosis or spinal instability. For example, TELD may not be a good choice for patients who show a herniated disc on radiographic findings but have long-term neurogenic intermittent claudication (NIC) and radiating leg pain that worsens with walking. On the contrary, patients with stenosis or grade 1 spondylolisthesis, but also presenting a positive SLR test of less than 45 degrees or no NIC symptoms before may be considered good indications for TELD [72] (Figs. 3 and 38).

Although radiological findings are important, clinical findings obtained by history taking and neurological examination can be more important in selecting appropriate patients and determining treatment methods. Among the clinical considerations for the indications of TELD, the most important thing is to determine whether soft disc herniation at the index level is the main cause of the patient's symptoms and signs.

2.2 Radiological Considerations

Radiologically, the appropriate indications for TELD are soft disc herniations, which compresses the nerve corresponding to the patient's symptoms and signs without severe stenosis or significant spinal instability.

It would be difficult to discuss contraindications as more advanced techniques are being developed to overcome many demanding and challenging cases. Cases of grade II spondylolis-

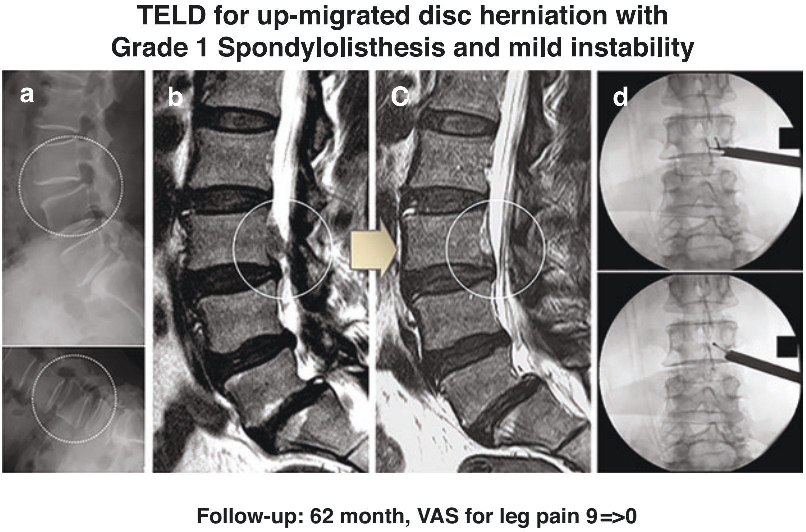


Fig. 3 TELD for up-migrated disc herniation with grade 1 Spondylolisthesis. A 54-year-old female patient presented with right leg radiating pain. Preoperative radiologic study showed highly down-migrated disc herniation and grade I spondylolisthesis without significant instability (**a**, **b**). She had never had intermittent claudication before. Complete removal of the herniated disc fragments was achieved by TELD without sacrificing any posterior spinal structures (**c**, **d**). Her follow-up duration was about 5 years. The final VAS score for leg pain was 0. GI Spondylolisthesis patients without NIC

thesis with significant instability and bilateral foraminal stenosis with severe central stenosis might be contraindications of TELD. In patients with conjoined root, which makes it difficult to access through the foramen, there may be access through the contralateral foramen or decompression through the secondary axilla of the conjoined root (Fig. 4). However, most of the anomalies of nerves passing through the caudal area of the intervertebral foramen belong to the contraindications of TELD. If the amount of foraminoplasty required for access to the herniated disc fragments is too destructive, it would be a relative contraindication of TELD.

Any soft disc herniations can be indications of TELD as long as the primary cause of symptoms is the herniated disc and the locations are not inaccessible. But, the characteristics of disc herniation at the index level and several accompanying radiologic findings may affect treatment outcomes. According to published articles related to radiological prognostic factors, several preoperative findings, such as protrusion type, smaller-sized herniated discs, central location of herniation, central located high-canal compromised herniation, migrated herniation, axillary type herniation, high-grade migration, concurrent lateral recess stenosis, Pfirrmann grade III, higher disc height index, larger sagittal range of motion, segmental kyphosis of index level, high grade of disc degeneration of adjacent level, and presence of Modic change were associated with unfavorable outcomes of TELD [38, 41, 57, 59, 64–66, 68, 70, 73–76].

Among these factors, central zone disc herniation, migrated disc herniation, and axillary type herniation were mainly related to surgical failure [38, 57, 59]. These surgical failures can be said to have a lot to do with the technical aspects related to the accessible range of the endoscope. In addition, factors related to surgical failure can be evaluated as technically demanding or prone to mistakes. For the development of TELD, a challenging attitude will be required rather than giving up by excluding these factors from indications.

Many of the factors described above were findings from studies related to recurrence, and the factors related to recurrence were not significantly different from those of open microdiscectomy [77, 78].

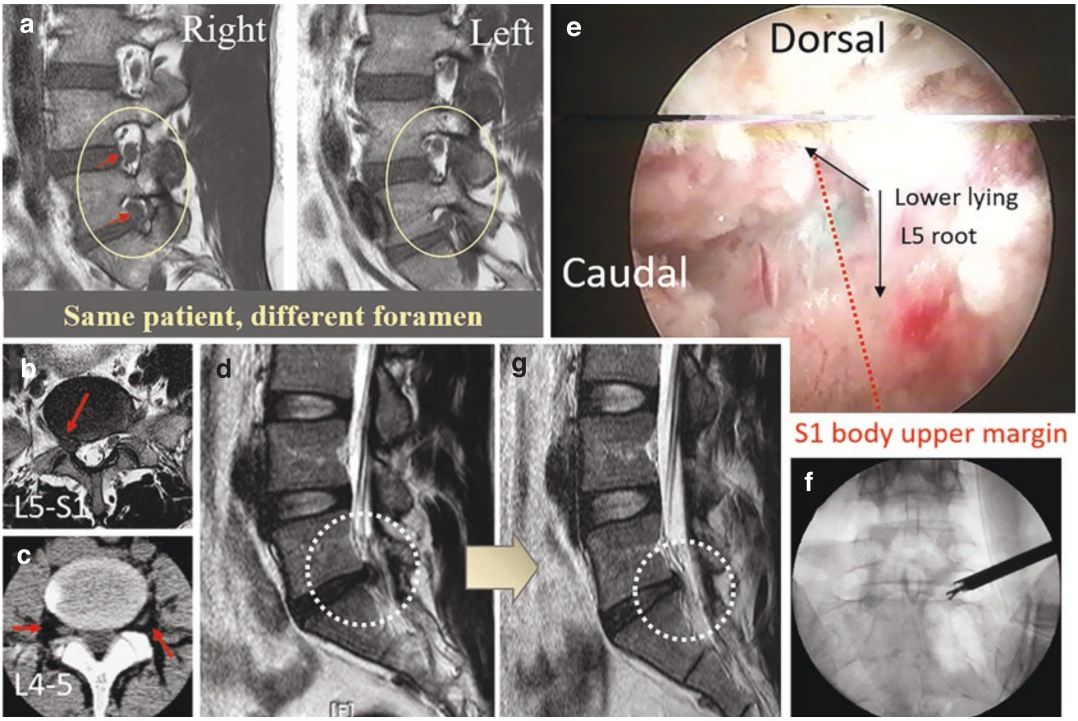


Fig. 4 A case of conjoined nerve root. A 26-year-old male patient presented with severe radiating pain in the right lower extremity. Preoperative radiologic studies showed disc herniation located in the subarticular zone at L5-S1 level (**b**, **d**), conjoined root at L4–5 level (**a**, **c**), and suspicious conjoined root at L5-S1 level with relatively lower lying L5 exiting root at L5-S1 level (**a**, **b**). A conjoined root was identified in the endoscopic field of view at L5-S1 level (**e**), and the working cannula could not enter the intervertebral foramen during TELD (**e**, **f**). Successful removal of the herniated disc was performed with an extraforaminal procedure through the secondary axilla without any specific sequelae (**g**). However, it was a very demanding procedure. When planning a TELD, it is always necessary to check the shape of the left and right intervertebral foramen on the MRI to check for anomalies of the exiting nerve root

Protruded disc herniations were reported to be worse prognostic factors for both recurrence and clinical outcome than extruded disc herniations, and smaller-sized herniated discs were reported to be more associated with early recurrence than larger-sized herniated discs [66, 70, 73, 74]. In the classification according to the shape of disc herniation, the degree of disc herniation and nerve compression are usually more severe in the case of extrusion than in protrusion. Therefore, these findings suggest that the more severe disc herniation is selected for treatment by the surgeon, the better the clinical outcome is likely to be obtained. It is considered to be a matter to pay particular attention to at the beginning of the learning curve. Extruded disc herniations would be better indications than protruded disc herniations, and transannular herniations might be better indications than contained disc herniations.

The studies published in relation to the radiological prognostic factors described above included only recurrent cases or cases that underwent early reoperation, or included only the last clinical results without knowing whether reoperation was performed. It has been difficult to find studies that identify prognostic factors, including both cases of surgical failure and the final clinical outcomes of patients.

In author's prospective study of case series analysis for prognostic radiological factors of TELD for intracanal extruded disc herniation (81 consecutive patients, mean age 35.8 years with range 16–82, 51 males, mean follow-up 24 months, including 24 cases of migrated disc herniation, 19 cases of severe volume of herniation more than 66% canal compromising, 10 cases of concurrent stenosis), there were three major factors predicting an unfavorable outcome: (1) calcifications around the base of herniation (calcifications of annulus or posterior longitudinal ligament, endplate osteosclerosis) ($P = 0.009$), (2) prominent Modic change ($P = 0.002$), and (3) incomplete removal of extruded herniation as seen on the immediate postoperative MRI ($P = 0.004$) (Fig. 5). In this study, patients were selected based on the clinical and radiological indications described above, and unsuccessful outcomes (6.2%, 5 cases) defined as: (1) Failure of procedure leading to open surgery due to remaining disc fragments (2 cases), (2) No significant improvement of VAS or ODI (<50% improvement of their initial score, 3 cases), (3) Macnab ratings of fair or poor (same patients of No. 2 criteria). In author's study, except for the three factors described above, other preoperative findings such as age, gender, level, direction, degree of migration, volume of the herniated disc, signal intensity on magnetic resonance imaging (MRI), size of annular defect, and presence of accompanying stenosis had no statistically significant correlation with unsuccessful outcomes. TELD is an effective treatment for extruded intracanal disc herniation in appropriately selected patients. Complete removal is essential to achieve successful outcomes. In cases with concurrent calcifications around the base of herniation and the conspicuous vertebral body marrow changes, it would be better to perform more meticulous procedures or to choose the other surgical method according to the severity.

Identification of prognostic factors is important in establishing indications and increasing the success rate by selecting appropriate patients, and also in suggesting the direction of technological improvement of treatment methods.

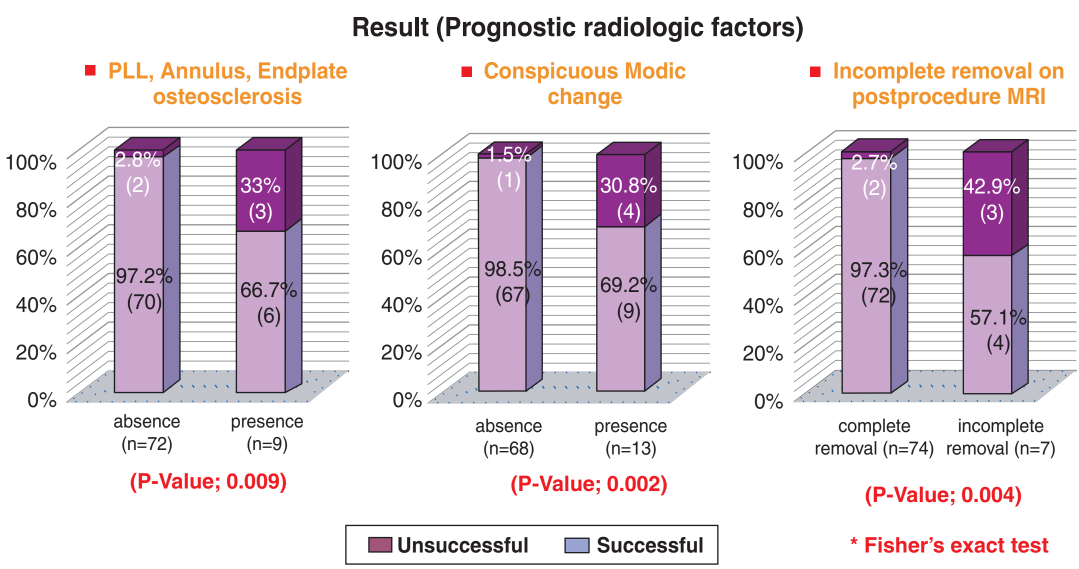


Fig. 5 Radiological prognostic factors in author's prospective study of case series analysis. Calcifications around the base of herniation (calcifications of posterior longitudinal ligament or annulus with endplate osteosclerosis), prominent Modic change, and incomplete removal of herniated disc were identified as unfavorable prognostic factors

2.3 Technical Considerations and Accessible Range of the Endoscopic Forceps

In selecting an appropriate patient for successful TELD, clinical and radiological findings as well as technical aspects should be considered. The indications for TELD should include technically feasible. That is, the herniated disc must be within the accessible range of the endoscopic forceps.

The accessible ranges of the endoscopic forceps are closely related to the characteristics of the instrument selected, the approach method performed and the techniques employed, the anatomical characteristics of the index level, the selected entry route, and the surgeon's position on the learning curve. Although there are relatively many and extensive contents to be known and discussed, understanding and knowledge of these accessible ranges and limitations in the application of TELD treatment is very important and essential for appropriate patient selection and successful procedure.

The limitations of the accessible range in TELD procedures are mainly due to the anatomical characteristics of the intervertebral foramen and the dimension of the safe working zone. In addition, the limitation is due to the characteristics of the instrument based on this dimension and the characteristics of the procedure that requires an approach angle. According to several anatomical studies, the maximum safe canal diameter was reported to be less than 8 mm on average, and the average distance between the exiting root and superior articular process at the lower endplate level was reported to be 11.6 mm (8.1 mm at L1–2–15, 5 mm at L5-S1) [18–20]. Based on these anatomical studies, the endoscopes used for TELD have an outer diameter of about 6–8 mm and a working channel of about 3–4 mm inside (Fig. 6g). Endoscopic procedures are performed

Instruments – Forceps and Endoscope

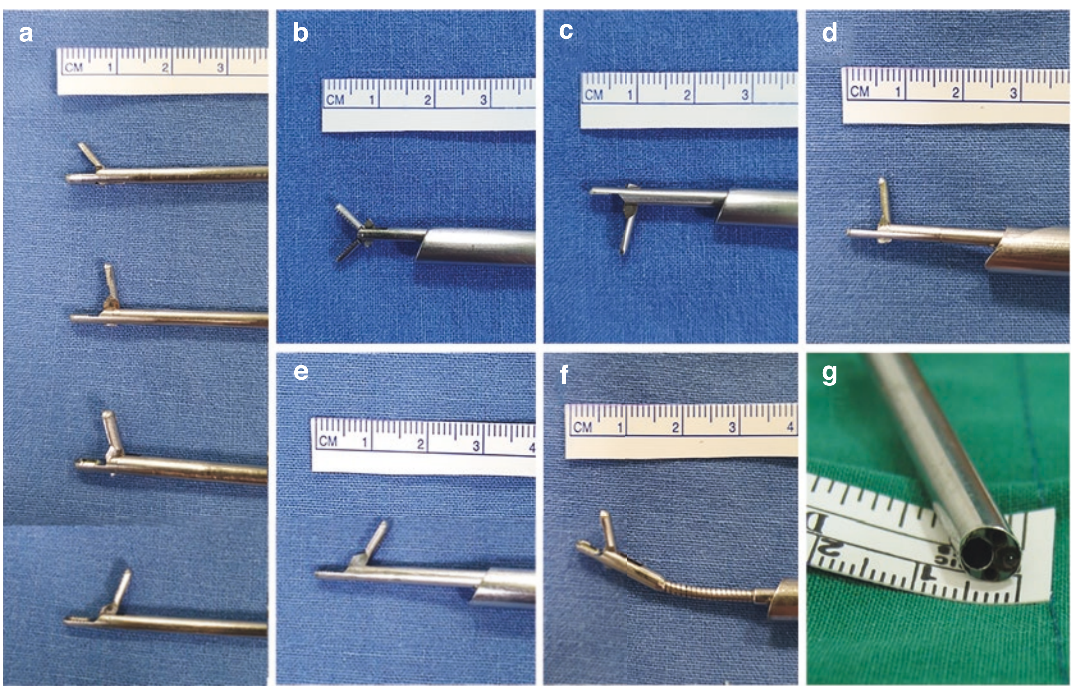


Fig. 6 Types and characteristics of endoscopic forceps (**a**–**f**) and structure of distal end of endoscope (**g**). In TELD, crocodile action forceps composed of stationary jaws and actuating jaws (**a**, **c**–**e**) are mainly used rather than double action forceps (**b**) because there are mainly unidirectional operations due to the characteristics of the posterolateral approach

using various tools that pass through this working channel inside the endoscope.

Among the tools that pass through this working channel, the most important tool to remove the herniated disc fragment is the endoscopic forceps. In TELD, crocodile action forceps composed of stationary jaws and actuating jaws are mainly used rather than double action forceps because there are mainly unidirectional operations due to the characteristics of the posterolateral approach (Fig. 6). The role of the actuating jaw of the endoscopic forceps is very important. Due to the characteristics of the access path of the transforaminal approach, the basic operation is to pull down and pull the prolapsed disc from the base of herniation. Therefore, it can be said that the actuating jaw of the endoscopic forceps plays the most important role in the process of retrieving the disc fragment.

The endoscopic forceps passing through the endoscopic portal were upgraded to gradually increase the thickness and length of the jaws, and it helped to widen the accessible range of the endoscopic forceps and to broaden the indications for treatment to some extent. However, if it is thicker than a certain level, it may block the view of the lens located below, making it difficult to perform precise and fine procedures. If the length of the actuating jaw of the endoscopic forceps is made longer, the reachable range could be increased. However, if it is longer than about 8 mm, it becomes difficult to open the jaws in a narrow space, making handling difficult. In addition, endoscopic forceps with too long actuating jaws are not useful because the tip of the elongated actuating jaw may be out of the endoscopic field of view during the procedure. Flexible curved endoscopic forceps can help, but they do not bend to the surgeon's side up to 90 degrees, and when entering deeply, most of them go out of the endoscopic field of view, so they are not very effective (Fig. 6f). Therefore, the maximum length of the forceps jaws in the endoscopic field of view is about 7–8 mm in terms of safety and effectiveness (Fig. 7a, b). The length and default open angle of the actuating jaw of the endoscopic forceps are closely related to the reachable range during actual treatment.

As a characteristic of the TELD procedure that requires an approach angle, the reachable distance is lost as much as the tangential value in the reference plane direction (dorsal direction) according to the approach angle and the progress of the entry, so the actual available reach of the endoscopic forceps in the dorsal direction would be less than 7 mm. If the endoscopic forceps are spread 90 degrees and approached horizontally, the reachable distance in the dorsal direction is

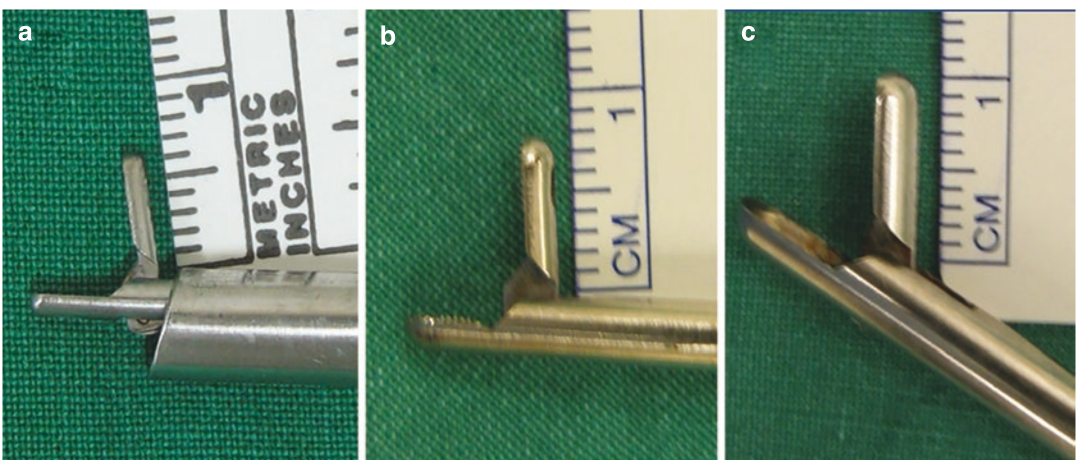


Fig. 7 Size and length of actuating jaw of endoscopic forceps. The safe and effective maximum length of the forceps jaws in the endoscopic field of view is approximately 7–8 mm (**a**, **b**). Large forceps passing only through the working cannula have a length of about 10 mm in the actuating jaw (**c**). Since the use of this large forceps is not an endoscopic field of view, it is recommended not to use it as much as possible

7–8 mm. If the forceps' maximum default open angle is 45 degrees, the distance becomes smaller. Assuming an approach at an angle of 30 degrees, the distance between the endoscopic forceps and the target point located on the dorsal side becomes about 3 mm apart for every 5 mm lateral distance (Fig. 8). Given the finite length of the actuating jaw of the endoscopic forceps, this distance of about 3 mm would not be small. In addition, this lateral distance of about 5 mm corresponds to a distance between the mid-pedicular line and the medial pedicular line.

Depending on the approach trajectory including the angle of approach, the range of the reachable space of the endoscopic forceps will be different (Fig. 9). The flatter the approach angle of the endoscope, the easier it is to access the intracanal epidural space. However, the flatter it is, the more difficult it is to access the intradiscal loose disc particles of the herniation base. If the approach is too horizontal, the exiting root and the traversing root may be injured due to the effect of narrowing the dorsoventral width of the triangular safe zone (Fig. 9b).

Even if it enters at the same angle at the same level, the operating range of the endoscopic forceps varies depending on which point on the annulus surface it enters from (Fig. 10). Although it is an entry point with a distance difference of only 5–6 mm, there is a relatively large difference between the working space range of the forceps passing through the endoscope entered from the mid-pedicular line and the case of entered from the medial pedicular line (Fig. 11). TELD procedures can be said to be fine and delicate operations using small instruments that have to pass through a relatively narrow window, and a distance of only a few millimeters can determine the failure or success of the procedure. Therefore, the procedure should be performed as close to the target as possible with appropriate access.

Technical methods for approaching the endoscope closer to the target and increasing the reachable range of the endoscopic forceps include accurate targeting and appropriate access, effective use of obturator insertion technique, proper working cannula placement, adequate annular releasing, levering and rotational movement of

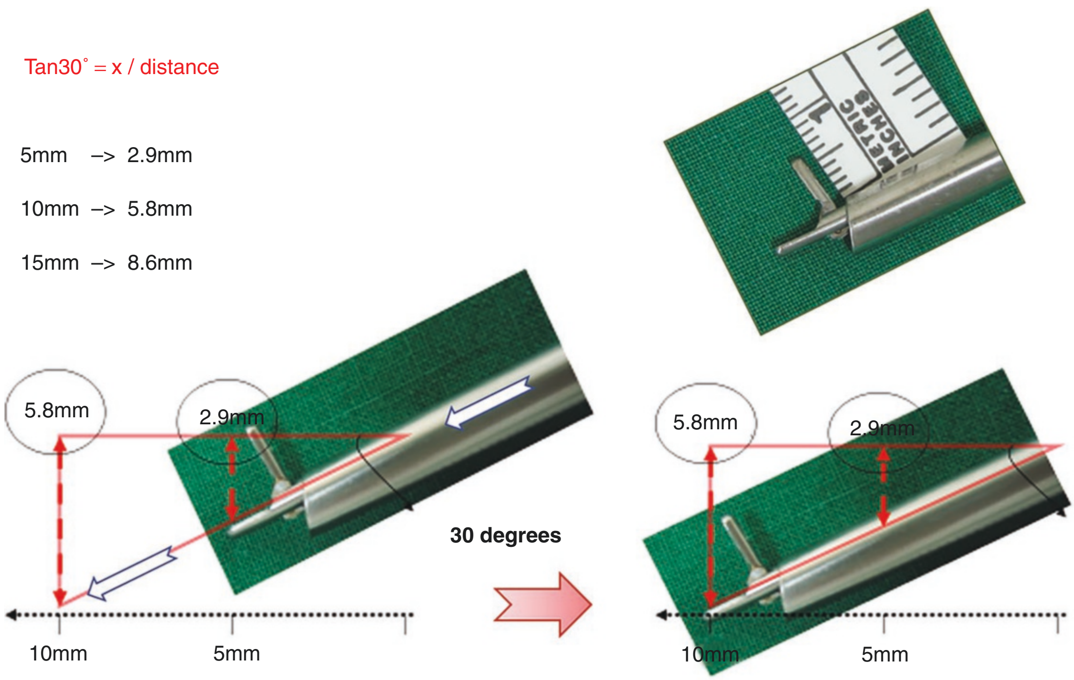


Fig. 8 Schematic drawings of the tangential value according to the approach angle and the progression of entry

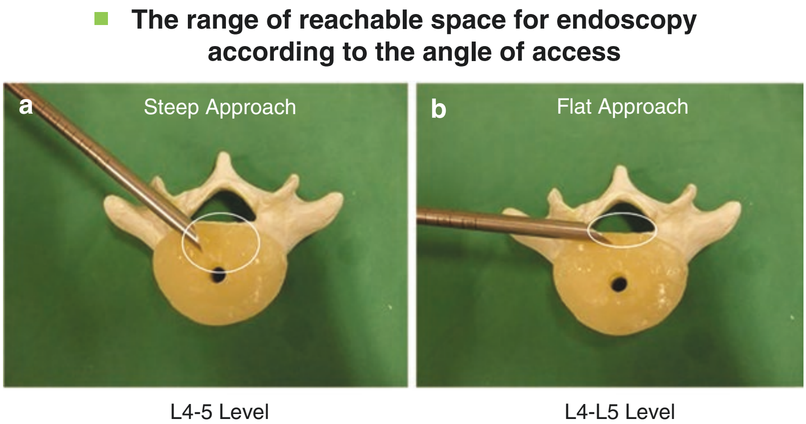


Fig. 9 The range of reachable space for endoscopy according to the angle of access. If the approach angle is too steep, only indirect decompression can be achieved (**a**). When approaching too horizontally, there is a possibility of injury to the exiting root and the traversing root due to the effect of narrowing the dorsoventral width of the triangular safe zone (**b**)

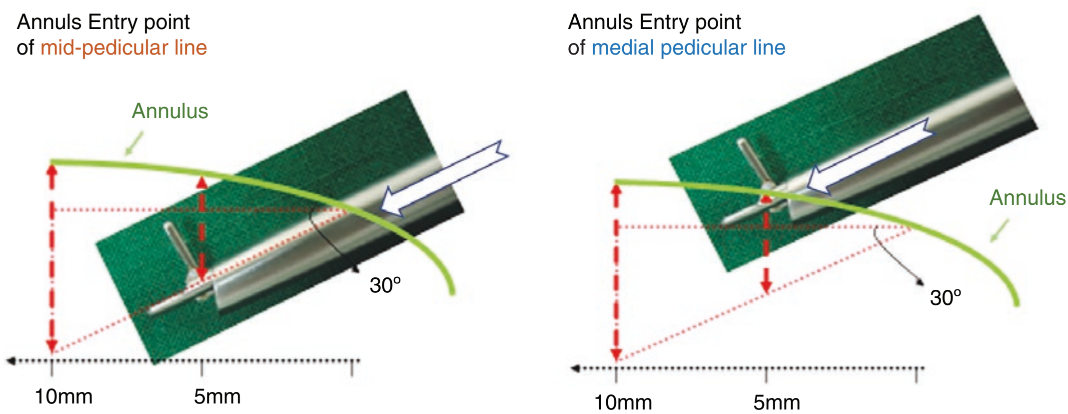


Fig. 10 Schematic drawings of difference in the accessible range of endoscopic forceps depending on whether the annulus entry point is the mid-pedicular line or the medial pedicular line

the endoscope, appropriate selection of endoscopic tools, and performing foraminoplasty. Among them, the use of appropriate access trajectory including the entry point and approach angle, the effective utilization of the obturator, and the proper positioning of the working cannula are crucial processes as methods to approach the target closely. Effective use of obturator plays an important role in determining the annulus entry point. As methods for expanding the treatment area and increasing the accessible range of the endoscopic forceps, adequate annular releasing and levering of the endoscope also contribute, but foraminoplasty plays the biggest role.

Given the limitations of the accessible range mentioned above, it would be very difficult to completely capture the herniated disc fragments if the center of the extruded fragments was migrated more than 7 mm away from the endplate level. However, even these cases are not included in the contraindications of TELD. In these cases, it is necessary to advance the endoscope to the epidural space outside the annulus, and cases with a very large foramen may be

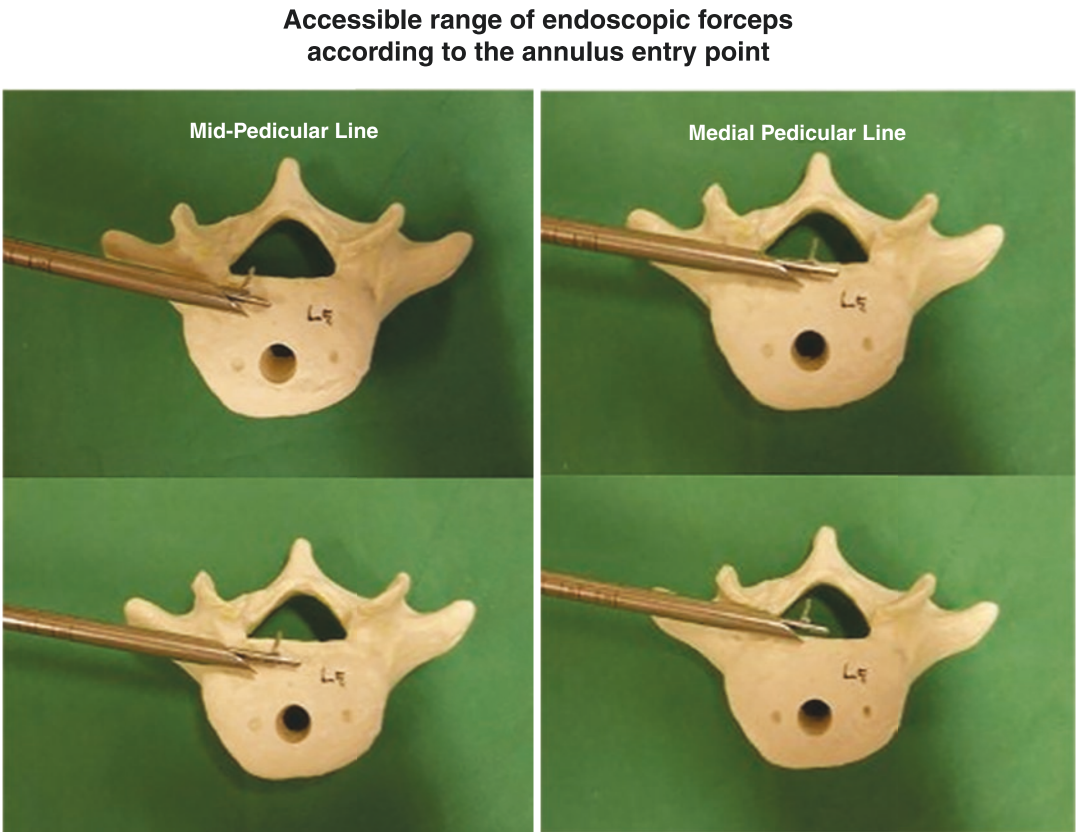


Fig. 11 Accessible range of endoscopic forceps depending on whether the annulus entry point is the mid-pedicular line or the medial pedicular line. The reachable range of the endoscopic forceps may vary depending on the annulus entry point as well as the approach angle

selected, but in most cases, access is possible if foraminoplasty is performed. Foraminoplasty is an important process that allows the TELD procedure to be performed completely through the intervertebral foramen, facilitates access to the displaced herniated disc and epidural space, overcomes obstacles, and increases the access range of endoscopic forceps.

Besides the approach techniques, the accessible range of endoscopic forceps depends on differences in anatomical structures according to the index level and the selected access route (foraminal or interlaminar window). Compared to the lower lumbar vertebrae, the upper lumbar vertebrae have characteristics such as narrower lamina width, lamina overhanging the disc space, wider space between ventral surface of superior facet and the dorsal surface of vertebral body, more sagittal orientation of facet, and deeper superior vertebral notch above the pedicle (Fig. 12). The upper lumbar disc and upper lumbar vertebrae are characterized by a concave dorsal surface (Fig. 12d). As it goes down to the lower lumbar region, the opposite characteristics proceed, and the concavity of the dorsal surface of the vertebral body and disc disappears, and the facets become larger and thicker than those of the upper lumbar region. In the upper and lower lumbar regions, the triangular safe zone has a slightly different triangular shape depending on the travel angle of the exiting nerve root corresponding to the hypotenuse, and the width of the dura is also slightly different. The distance from the exiting nerve root to the superior articular process usually gradually decreases from the lower lumbar level to the upper lumbar level [20].

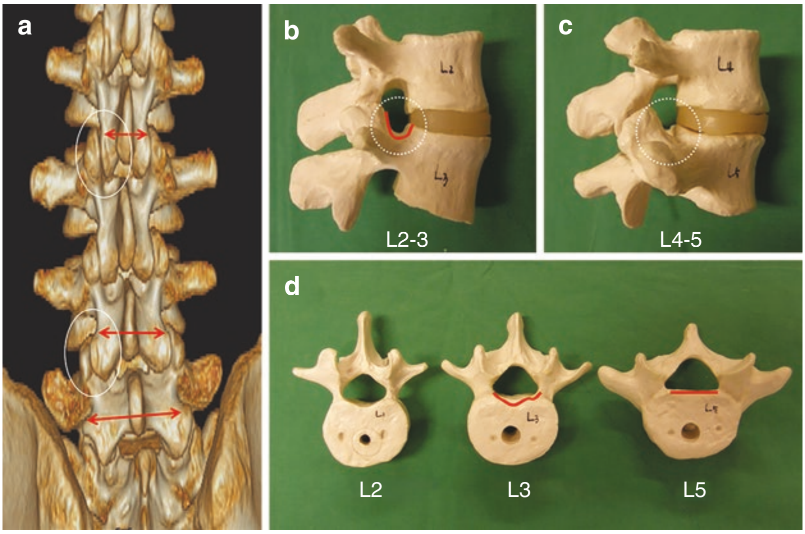


Fig. 12 Characteristics of upper and lower lumbar spine. The upper and lower lumbar levels show differences in lamina width (**a**), facet joint size and orientation (**a**), superior vertebral notch depth (**b**, **c**), and concavity of the dorsal surface of the disc and vertebral body (**d**). It is necessary to understand the difference between the upper and lower lumbar spine because the approach route, the approach trajectory including the initial target point and the approach angle, and the required approach techniques are different according to the characteristics of each index level

Depending on these characteristics of each index level, the approach route, the approach trajectory including the initial target point and the approach angle, and the required approach techniques may and should be different. Even if the approach is at the same angle, the range of the reachable space of the endoscopic forceps varies according to the index level (Fig. 13). In order to enter the epidural space in the endoscopic procedure for lower lumbar disc herniation, it is necessary to approach at a flatter angle or to lever the working cannula more horizontally than in the case of upper lumbar disc herniation (Fig. 13). In TELD for upper lumbar disc herniation, the accessible range of endoscopic forceps is relatively wide because it is easy to enter the epidural space outside the annulus and to access the space beyond the disc level (Figs. 13 and 14). The reason may be simply due to the wide foraminal dimension, but also due to the sagittal orientation of the facet, the small pedicle diameter, the concavity of the disc dorsal surface, and the deep superior vertebral notch (Fig. 12b, d). This can be a clue to the area where foraminoplasty is required. At the upper lumbar level, the exiting nerve root has a lot of vertical travel, and the dural sac is relatively wide laterally and has compact neural elements inside. Therefore, caution should always be taken to avoid injury to the dura and nerves when approaching and levering the working cannula.

Unlike the other levels, the L5-S1 level is usually located ventral and below the iliac crest. The facets are large and have a horizontal orientation in the coronal plane. In addition, the L5-S1 level has a wide interlaminar space, and the lamina has a horizontal orientation in the sagittal plane (Fig. 12a). Due to these characteristics, transforaminal approaches to the L5-S1 level have more limitations compared to other levels. If TELD is performed on patients with a narrow width between the bilateral iliac crest, the approach will be too steep. In order to approach at a relatively low angle, the start of the entry must be quite cranial, and this approach makes it difficult to access the intracanal area completely through the intervertebral foramen. That is, a partially transforaminal procedure is performed rather than a complete transforaminal in the true sense. Although the topic of this chapter is the transforaminal approach, it should be borne

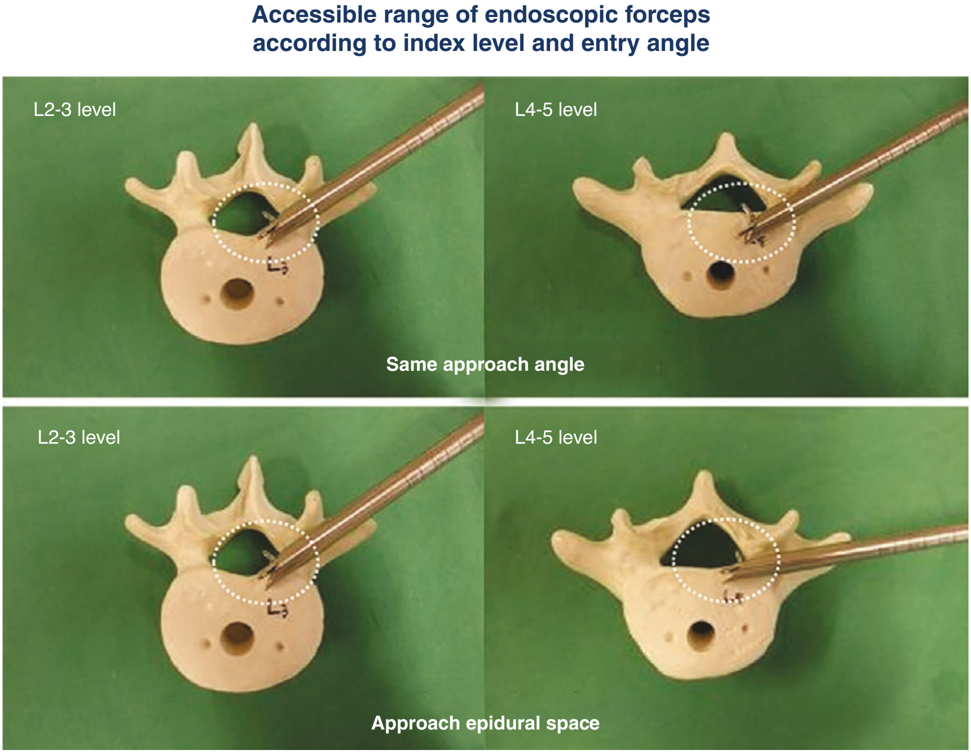


Fig. 13 Accessible range of endoscopic forceps according to the index level and approach angle

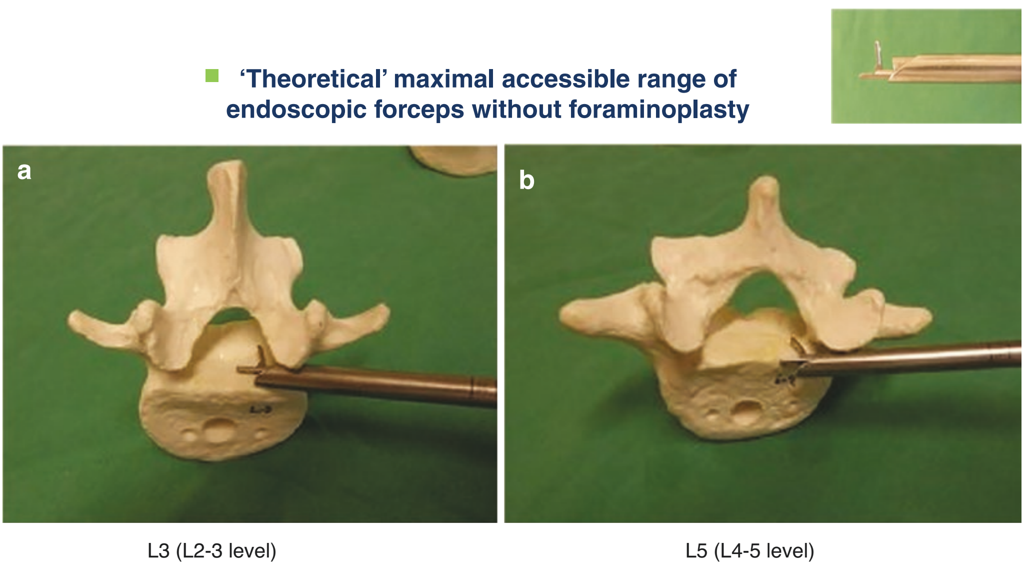


Fig. 14 The theoretical maximum accessible range of endoscopic forceps at L2-3 level (**a**) and L4-5 level (**b**) without foraminoplasty. The maximal accessible range of endoscopic forceps without foraminoplasty varies according to the index level. In actual treatment, since the exiting nerve root often runs vertically close to the superior articular process at the upper lumbar level, extreme care must be taken to lever the working cannula as shown in figure (**a**) above. Therefore, the expression "theoretical" is used

in mind that spinal endoscopy uses two windows: transforaminal and interlaminar. In fact, in L5-S1 level endoscopic treatment, it is often useful to use the interlaminar approach using the characteristics of the wide interlaminar space and the horizontal orientation of L5 lamina [31, 79–81]. However, when comparing the transforaminal and interlaminar approaches, the transforaminal approach has many advantages. There is no nerve retraction process in the transforaminal approach, and the possibility of dura and nerve injury, the degree of damage to the yellow ligament and annulus, and the possibility of epidural scarring are lower than that of the interlaminar approach. In addition, the working time in the epidural space, which is the most painful section during the endoscopic procedure under local anesthesia, is shorter during the transforaminal approach. Therefore, if a successful approach is feasible, it is considered to be good to use the transforaminal approach.

If the approach trajectory is well established and the foraminoplasty technique is used, successful TELD can be achieved even at the L5-S1 level in many cases [36, 81–83]. In the case of women, the height of the iliac crest is relatively low, the lumbosacral lordotic angle is often large, and the distance between the iliac crests on both sides is relatively far, so transforaminal approaches are relatively easy for many female patients (Fig. 15).

In TELD for L5-S1, the foraminal zone and subarticular zone are relatively less difficult to access than the central zone due to the lateral location of the lesions (Figs. 16 and 17). Successful TELD for L5-S1 level central zone disc herniations is feasible in selected cases and usually requires foraminoplasty (Fig. 18). In the case of central zone L5-S1 disc herniation, where the amount of foraminoplasty required for TELD is too destructive to the facet joint with a narrow gap between the bilateral iliac bones, it may be a relative contraindication. Highly up-migrated disc herniations at L5-S1 level are also considered relative contraindications. In the TELD procedure for L5-S1 level, most of the access trajectory is directed from the cranial to the caudal because of the obstacles of overlying iliac bone. Accordingly, in the case of up-migrated disc herniation at L5-S1 level, there is a high possibility that the herniated disc fragment is out of reach of the endoscopic forceps through the transforaminal approach. It is recommended to use an interlaminar approach for highly up-migrated disc herniation at L5-S1 level (Fig. 19).

Equipment upgrade is important to increase the reach of endoscopic forceps, and further efforts are needed for equipment development in the future. Given the above-mentioned limitations of the endoscope and the problems such as forceps out of sight, it is worth considering the development of a flexible endoscope and upgrading to an endoscope capable of adjusting the optic angle of the endoscope.

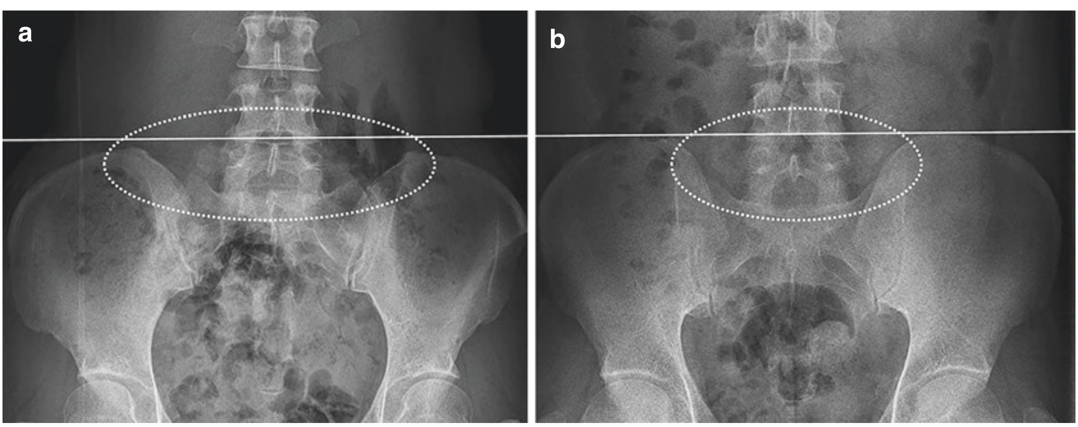


Fig. 15 Characteristics of female (**a**) and male (**b**) pelvic structures related to the iliac bone. In general, women are more easily treated with transforaminal approaches than men. Even with similar iliac crest heights, the distance between the bilateral iliac crests facilitates TELD procedures for women (**a**)

TELD for L5-S1 level (Foraminal zone)

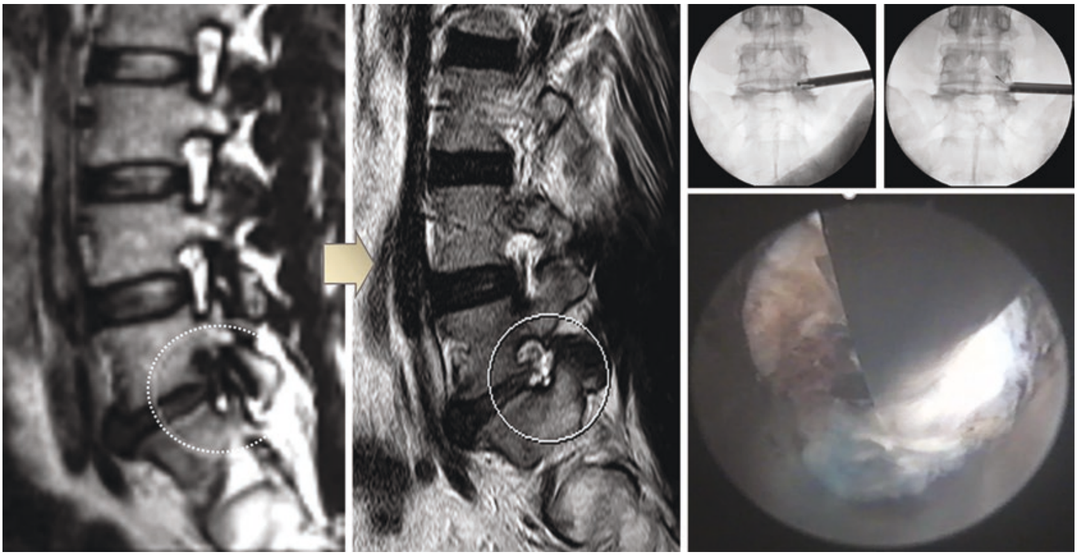


Fig. 16 A case of successful TELD for foraminal disc herniation with foraminal stenosis at L5-S1 level. A 44-year-old male presented with severe radiating pain in the lower extremities. TELD achieved complete decompression with foraminoplasty using an endoscopic drill and electric shaver

TELD for L5-S1 level (Subarticular zone)

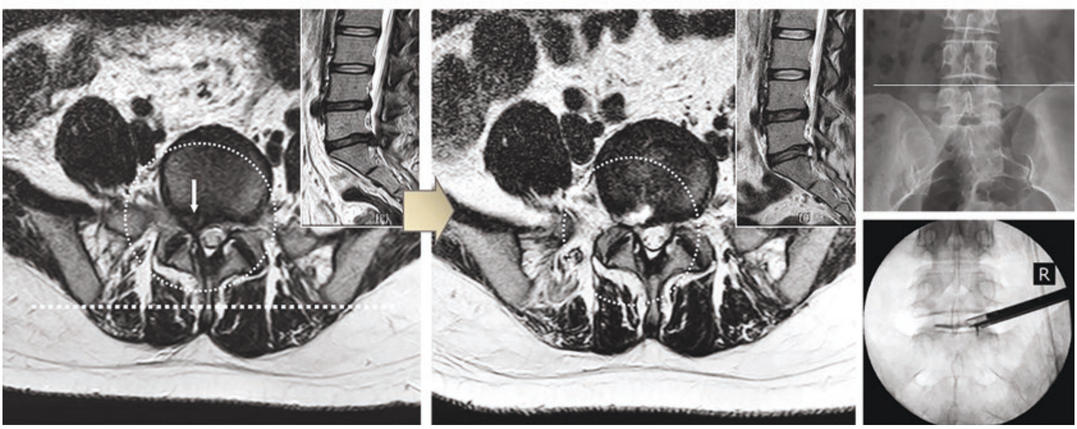


Fig. 17 A case of successful TELD for lumbar disc herniation of subarticular zone at L5-S1 level. A 21-year-old female patient presented with right leg radiating pain. Complete herniated disc removal was performed by TELD

The accessible range of the endoscopic forceps can also be determined by the surgeon's technical capabilities on the learning curve. The treatment results of TELD are related to the surgeon's experience and skill [57–60]. Indications would also be expanded depending on the surgeon's technical competence and proficiency. Since the indications for treatment would be altered according to the accessible range and limitations of each surgeon's endoscopic forceps, it is necessary to know how far they can reach and also to make efforts to gradually expand the range.

The success of TELD in the treatment of lumbar herniated disc depends on whether the endoscopic forceps reach a location where the herniated disc fragments can be retrieved. If the location is accessible, it would be an indication; if not, it would be a contraindication (Fig. 20).

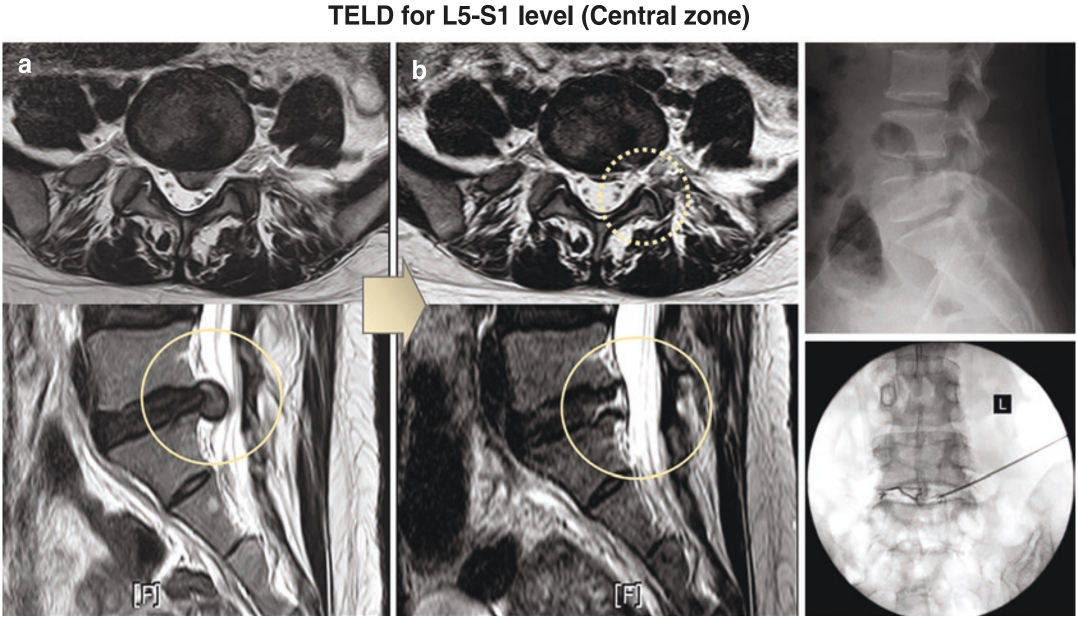


Fig. 18 A case of successful TELD for lumbar disc herniation of central zone at L5-S1 level (**a**). A 21-year-old female patient presented with right leg radiating pain. Complete herniated disc removal was performed by TELD (**b**). During the TELD procedure, foraminoplasty (round dotted line) was required to access the target area

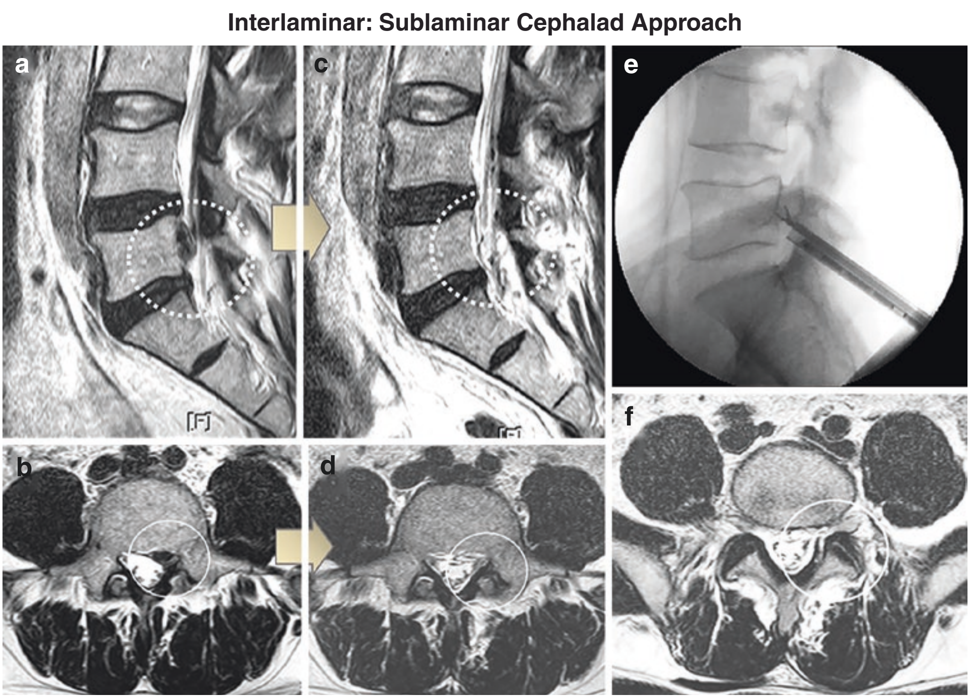


Fig. 19 A successful case treated with an interlaminar approach of endoscopic procedure for highly up-migrated disc herniation at L5-S1 level. A 47-year-old male patient presented with severe lower extremity radiating pain. Preoperative MRI showed severe migrated disc herniation (**a**, **b**). It was difficult to distinguish whether it was down-migrated disc herniation of L4–5 level or up-migrated disc herniation of L5-S1 level (**a**). Successful removal of the herniated disc was achieved by endoscopic procedure using the L5-S1 interlaminar window (**e**, **c**, **d**). Postoperative MRI showed detached ligamentum flavum according to the access route (**f**)

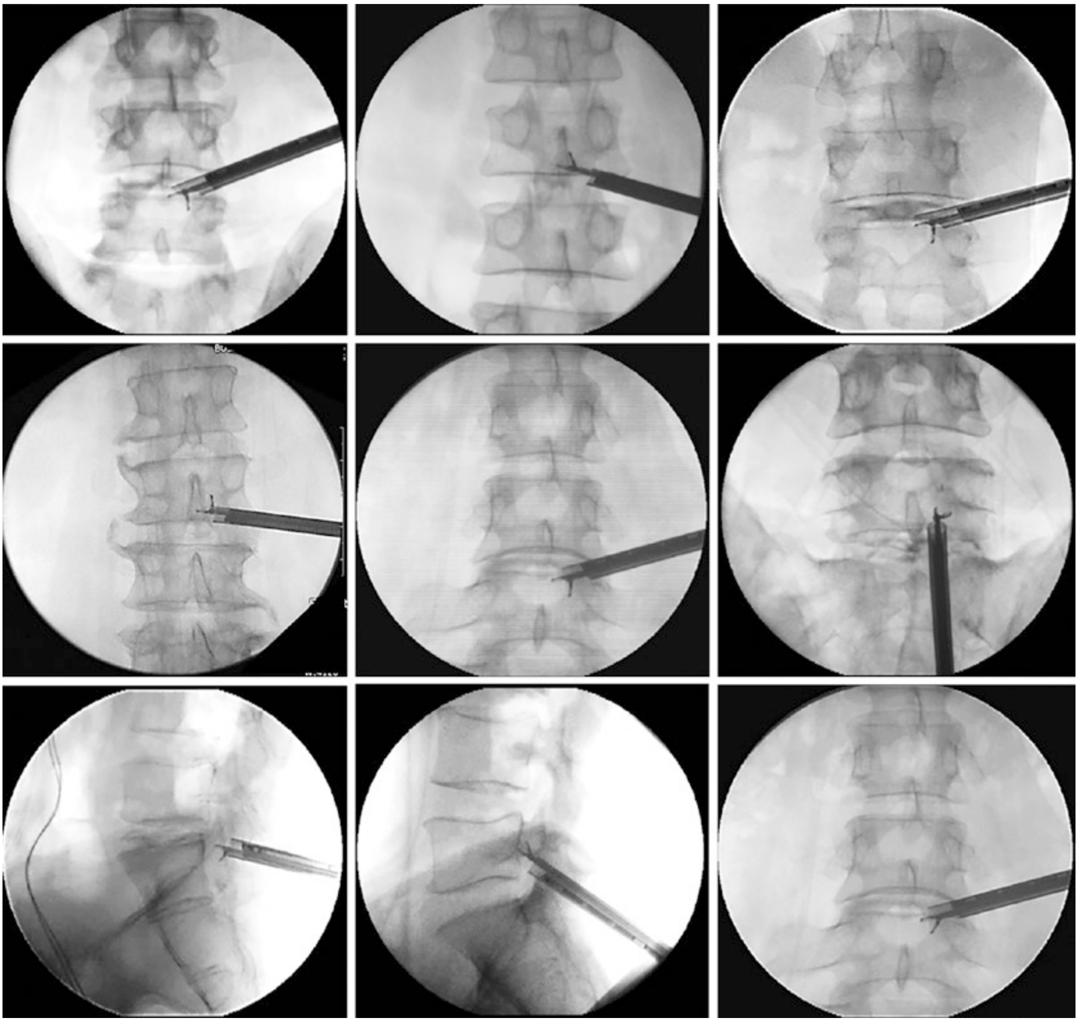


Fig. 20 Accessible range of endoscopic forceps. The indications for treatment would be different depending on the accessible range and limitations of endoscopic forceps for each surgeon. It is necessary to know how far endoscopic forceps can reach and also to make efforts to gradually expand the range

3 Surgical Technique

In order to achieve successful TELD, it is necessary to safely reach the target area and secure the endoscopic field of view. In addition to that, the endoscope must be approached close enough to remove the herniated disc fragments. Success or failure is highly dependent on whether the endoscopic forceps can reach a position where it can capture herniated disc fragments (HDF). Therefore, the important points for a successful procedure are: (1) appropriate use of the characteristics of equipment and tools, (2) accurate targeting process to access through appropriate trajectory, effective use of obturator insertion technique, and positioning of the working cannula as close to the target as possible, (3) efforts to secure clear vision and work within the endoscopic field of view, (4) utilization of additional techniques such as foraminoplasty, levering, and annular releasing, which are tips to approach the target point more closely, (5) effective method of working around the base of the herniated disc at the target point and how to remove the herniated disc without remaining herniated discs. In addition, it is necessary to properly utilize access techniques according to the disc herniation pattern of each patient and the characteristics of the spine structures at the index level.

The surgical steps of the usual TELD are performed in the following order: (1) Operative room and instruments setting, (2) Anesthesia and position of the patient, (3) Initial target point and skin entry point determination, (4) Needle and obturator insertion, (5) Placement of working cannula, (6) Subannular space decompression and annular releasing, (7) Foraminoplasty (Work of widening the foraminal window), (8) Fragmentectomy, (9) Conform the decompression, (10) Closure.

The order of No. 7, No. 8, and No. 9 above may be changed case by case. Foraminoplasty may be performed before subannular decompression. Foraminoplasty may be omitted. The order of subannular decompression and fragmentectomy can also be changed, and sometimes they are performed simultaneously. Fragmentectomy is usually performed after subannular decompression (inside to out tactics), but in some cases, subannular decompression may be performed after fragmentectomy (outside to in tactics).

3.1 Preoperative Setting, Positioning of the Patient, and Anesthesia

The proper preparation for effective and smooth TELD should include setting the operating room and instruments, sufficient anesthesia to provide a comfortable environment for the patient and operator, and safe and stable positioning of the patient. In addition, cooperation between the operating surgeon, anesthesiologist, nurse, and radiologic technician is required. A comfortable procedure can lead to perfect treatment results.

In the TELD, which is usually performed under local anesthesia, the patient is placed in the prone position. The prone position is more stable for the patient than the lateral decubitus position and provides the surgeon with easier handling of instruments. It is convenient to identify the midline and the zone of coronal plane through anteroposterior (AP) view monitoring using C-arm fluoroscopy whenever necessary during the procedure. If the lateral view is frequently monitored during the TELD, the procedure can be performed in the lateral decubitus position. The lateral decubitus position can be frequently used in endoscopic procedures with an interlaminar approach because it provides the surgeon with comfortable handling of the instrument.

The patient should be comfortable during the procedure. Although monitoring the patient's muscle strength and sensation can be important, it is not recommended to force the patient to tolerate the severe pain caused during the procedure due to shallow anesthesia. Pain in the course of TELD procedure under local anesthesia frequently occurs during the entry of the dilator and the working cannula into the annulus, during the procedure at the junction of the annular surface and the endplate near the midline, and during the procedure in the epidural space close to the nerves and around blood vessels.

Pain control during the procedure is a very important part for a successful procedure. The degree of pain that occurs during TELD can affect not only patient satisfaction but also successful procedure.

In the author's prospective randomized control study in which 51 patients (32 males and 19 females, mean age 37.3 years) were included, there were differences in the visual analogue scale (VAS) score during the endoscopic discectomy procedure, the satisfaction rate after the procedure, and the rate of complete herniated disc removal according to the anesthesia method. In this study, a comparative analysis was conducted between the group A patients who received local anesthetic just before the procedure by the surgeon through the access route and the group B patients who received interlaminar epidural block 30 min before the procedure by the anesthesiologist. Group A patients were given opioid analgesics whenever necessary during the procedure, and group B patients were administered appropriate sedatives and opioids as needed with the help of an anesthesiologist. The procedure was effective to relieve their radiating leg pain in all patients. The overall mean VAS score for leg pain decreased from 7.77 to 1.98 immediately after procedure, and to 0.55 finally (mean final follow-up: 12 months, $P < 0.05$). The intraoperative VAS scores of Group B were significantly lower than those of Group A. The mean intraoperative VAS score of Group B was 1.8. A total of 40% of group A patients and about 92% of group B patients had a VAS score of less than 5 points during the procedure (Fig. 21a). This difference was statistically significant ($P < 0.01$). A total of 19 (76%) group A patients and 25 (96.2%) group B patients answered that they would be willing to undergo the same procedure again (Fig. 21b), and there was a significant difference between the two groups ($P = 0.05$). All of group B patients responded that they are willing to recommend this procedure to other patients. Compared with group A, group B showed a tendency to have a higher rate of complete herniated disc removal on MRI after endoscopic discectomy ($P = 0.051$) (Fig. 21c). There were no statistical correlations between the intraoperative VAS score during endoscopic lumbar discectomy and the other factors such as gender, age, level, types of herniation, and access route.

In addition to epidural anesthesia, proper use of IV sedatives is very helpful in making the patient comfortable and reducing pain during the procedure, so that the procedure proceeds smoothly. Lidocaine is mainly used for epidural anesthesia, but bupivacaine or other local anesthetics may be used. When lidocaine is used, about 10 mL of 1% lidocaine is infiltrated from the skin along the entry track and a similar dose is injected to spread from the annular surface to the epidural area. As a sedative, Midazolam or Fentanyl may be used in an intermittent manner as needed. However, intravenous sedatives administered as continuous infusion with the help of an anesthesiologist have many advantages and are more effective. Dexmedetomidine is a selective adrenoceptor agonist and has sedative and analgesic effects without respiratory depression, so it is very helpful for endoscopic procedures. For conscious sedation, administration of Dexmedetomidine at a dose of 1 mcg/kg for 10 min as continuous infusion is started, and then the maintenance dose is followed by reducing it to about 1/10 of the dose. The dosage and speed of administration can be adjusted as needed

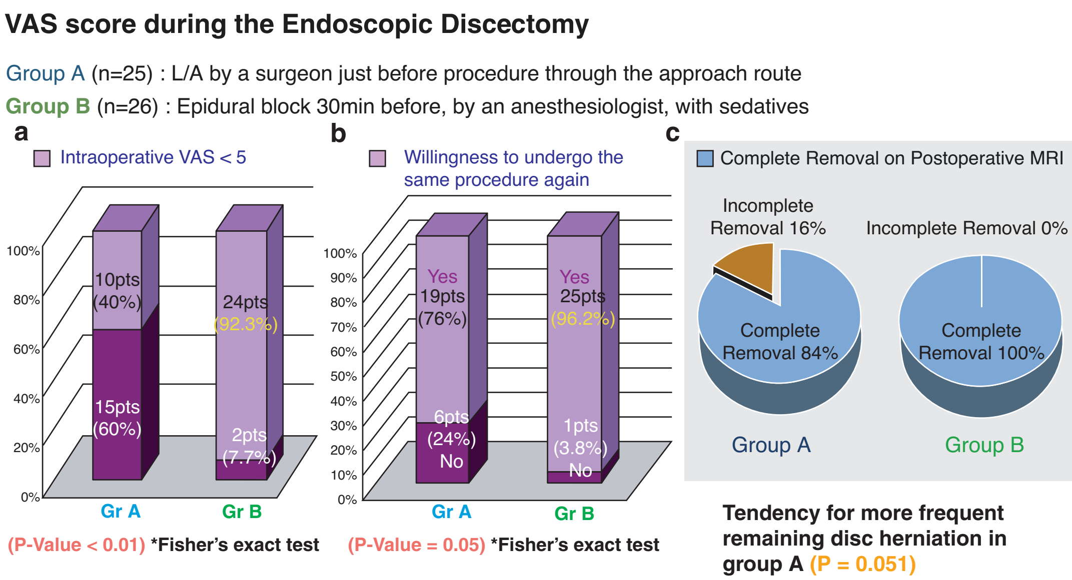


Fig. 21 VAS score during the course of endoscopic discectomy according to anesthetic methods in the author's prospective randomized control study. The difference in the VAS score of the patient during the procedure according to the anesthesia method (**a**) can affect not only the satisfaction of the patient after the procedure (**b**) but also whether the procedure is successful (**c**)

during the procedure. Experienced surgeons can perform the procedure in relatively deep sedation for a comfortable operation. However, when it is judged that it is necessary to monitor the patient's response in a procedure that requires attention, it is better to use a sedative in a low dose.

In TELD under local anesthesia, knowing how to minimize the patient's pain during the procedure and make the patient comfortable or tolerable is very helpful for successful results and smooth operation. In addition to the use of adequate epidural anesthesia and sedation, sufficient subcutaneous anesthesia, minimizing working time around the ganglion and in the epidural space, avoiding rapid pressure changes during procedures that cause pressure changes (such as injection of a contrast medium into the epidural or intradiscal space, speed control of irrigation fluid, and removal of a large volume of herniated disc), reassuring the patient, and warning in advance of painful steps are useful tips to reduce pain during the procedure.

3.2 Planning for Initial Access (Initial Target Point and Skin Entry Point Determination)

3.2.1 Primary (Initial) Target Point

The ultimate target area in TELD is where endoscopic forceps can grab and remove herniated disc fragments. However, the primary target point of entry at the beginning of the procedure is usually selected at a point on the annular surface located in the triangular safe zone. It is better to determine the initial target point as a point close to the HDF. In the case of disc herniation of the central and subarticular zones, it is necessary to determine the initial target area close to the medial pedicular line (MPL). The ideal primary (Initial) target point is a point close to the HDF and MPL located on the annular surface of the triangular safe zone. If it is difficult to determine this ideal point as the initial target point due to problems such as hypertrophied facet, narrow foramen due to disc height loss, horizontal oriented wide facet, and central zone disc herniation at L5-S1, foraminoplasty would be planned and the ventrolateral surface of the superior articular process can be selected as the initial primary target point.

3.2.2 Skin Entry Point Determination

The skin entry point should be selected from among the areas that can reach the initial target point described above without nerve injury or invasion of the peritoneal area. In addition, the direction and location of the herniated disc should be considered, and it would be better to be determined as a point that is easy to reach both around the base of the herniated disc and where the herniated disc fragments are located. It should also be determined as a point where foraminoplasty can be minimized.

In determining the skin entry point, the best tip is to go through the following four processes.

1. On the preoperative MRI axial image, draw a line from the initial target point (a point close to the HDF and MPL located above the annular surface of the triangular safe zone) through the ventral or ventrolateral surface of the superior articular process to the skin. At this time, this line should be drawn so that it does not pass through the nerve and peritoneum. Measure the distance from the point where this line meets the skin to the midline (Fig. 22a).
2. On the patient's skin, draw a craniocaudal line connecting points separated from the midline by the distance measured on the MRI. In the C-arm fluoroscopic true AP view, draw a horizontal line parallel to the index disc and select the point where the two lines cross as the primary candidate point for the skin entry point (Fig. 22b).
3. According to the direction of the herniated disc, it is necessary to select the skin entry point from the primary candidate point to the cranial side in the case of the caudal direction and vice versa in the case of the cranial direction. It is helpful to determine how much up or down the skin entry point is by drawing a line toward the center of the migrated disc fragment in the C-arm fluoroscopic true AP view (Fig. 22b, c).
4. Press the patient's skin while predicting the levering effect of the endoscope after entering

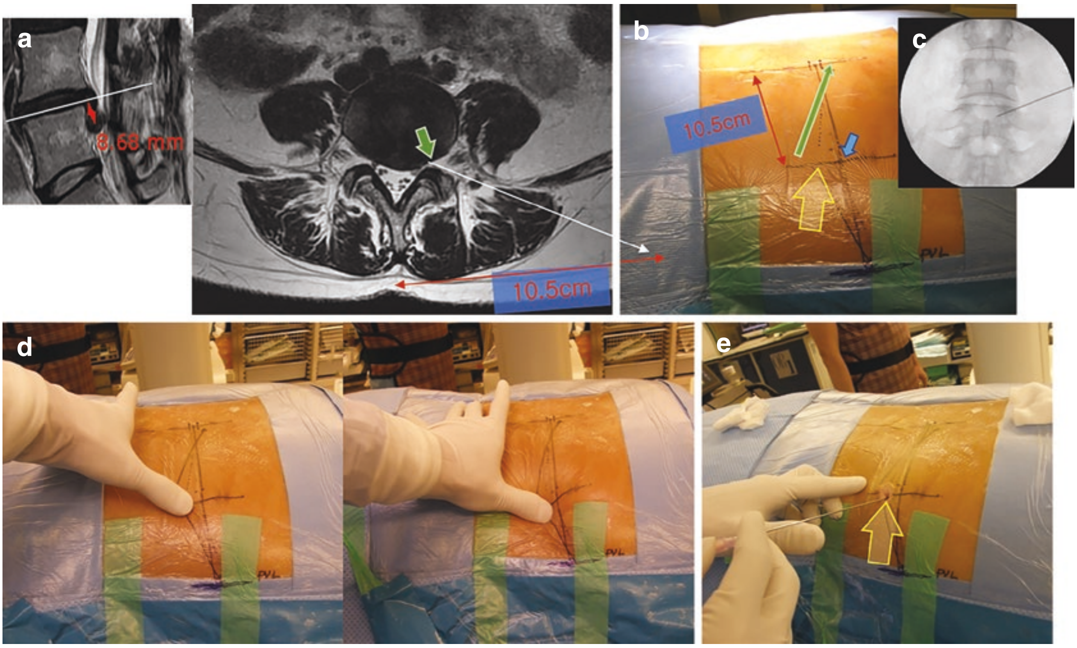


Fig. 22 Four processes of skin entry point determination. (**a**) Drawn line from the primary target point (green box arrow) through the ventrolateral surface of the superior articular process to the skin and measured distance from the point where this line meets the skin to the midline. (**b**) Primary candidate point (small blue box arrow), inclined trajectory line on coronal plane (green arrow line) drawn with reference to the fluoroscopic AP view (**c**), and final skin entry point (yellow box arrow). (**d**) Predicting the levering effect by pressing the patient's skin. (**e**) Determined final skin entry point

the working cannula. The final skin entry point is determined by examining the accessibility of both the herniated disc fragment and the subannular space around the base of the herniated disc. Specifically, the final skin entry point is determined as a point that is expected to be accessible to the subannular space among the points where the herniated disc fragment can be removed using foraminoplasty and levering effect later (Fig. 22b, d, e).

In the No. 1 process, a line passing through the ventral bony portion rather than the ventral surface of the superior articular process may be drawn when planning the foraminoplasty.

If the skin entry is too medial, the entry angle becomes steep and only the inner space of the disc is accessible, so it is difficult to remove the extruded disc and only indirect decompression might be achieved (Fig. 9a). When approaching at a flat angle from the side too much, it may be easy to access the space outside the annulus inside the canal, but the dorsoventral width of the safe triangular zone becomes narrower and nerve injury could occur (Fig. 9b).

Considering a safe approach that avoids nerve and peritoneal injury and the implementation of subannular decompression near the base of the herniated disc, it would be good to select medial side as the skin entry point within the range that can reach the HDF using the levering effect.

3.2.3 Inside-Out Tactic or Outside-In Tactic

In planning the sequence of TELD procedures, it is necessary to decide whether to proceed as an inside-out tactic or an outside-in tactic. Inside means inside the disc. Outside is the space outside the disc, which means the epidural space or the space outside the annulus and the external space around the disc. In the inside-out, the endoscope enters the inside of the disc first to perform the necessary decompression work in the subannular space, followed by the work in the outer space. Decompression of the space outside the annulus and the epidural space is performed using an annular defect site from the inside or from the side while retreating from the inside. Outside-in goes the other way around. Inside-out or outside-in is not a special technique, but rather a tactic that determines the order of the procedure to achieve an effective goal. Inside-out and outside-in can proceed simultaneously. It would be ideal if the working tube is inserted directly into the annular defect site and the epidural space and the inner disc space are resolved at the same time. But in fact, even in these cases, it is more advantageous to solve the inner side of the disc first. Inside-out tactic and outside-in tactic may be used interchangeably. After the inside-out, outside-in into the epidural space may be performed again as needed or according to a plan, or vice versa.

In general, it is more stable and advantageous to proceed with the inside-out tactic. When proceeding with the inside-out tactic, the bleeding time that obscures the endoscopic field of view is less than that of the outside-in, and it has the advantage of reducing the time of the epidural space work that can cause relatively severe pain during the procedure under local anesthesia. In addition, stable anchoring of the working cannula and securing of a working space are made at the beginning of the procedure, and the removal of intradiscal loose disc fragments in the subannular space, which can cause recurrence and residual back pain, can be carried out without being pressed for time. If only fragmentectomy is not insisted on, the basic tactic can be said to be inside-out.

However, sometimes it is necessary and advantageous to perform an outside-in tactic with the working cannula positioned outside the disc. If it is difficult to access through the foramen close to the medial pedicular line, an outside-in tactic should be used to perform the foraminoplasty first. Outside-in tactics are often used for foraminoplasty first in TELD for migrated disc herniations. However, if access to MPL is possible at the time of initial entry during TELD for migrated disc herniation, it may be better to proceed inside to out tactic. This is because, if the herniated disc fragment is not removed from the annular defect site, the prolapsed disc fragment can be removed after performing foraminoplasty by retreating the working cannula. Outside-in tactic is also useful when it is safe to enter the disc after partial decompression before entering the disc, as in the case of severe huge volumes of central disc herniation of the upper lumbar spine. In addition, when performing TELD for sequestrated disc herniation of severe nerve compression, outside-in tactic can be used if performing fragmentectomy first is advantageous for the procedure. This is mainly the case of formal disc herniation or up-migrated lateral disc herniation.

3.2.4 Pitfalls to Watch Out for

Before starting the procedure, it is always good to check the access route of the planned procedure again through the radiographic image before the procedure. The shape of the left and right intervertebral foramen should be carefully observed on MRI to check for anomalies of the exiting nerve root lying low in the caudal portion of the neural foramen, such as a conjoined nerve root. In this case, an interlaminar approach or access through the contralateral foramen may be planned by changing the access route (Fig. 34). When planning TELD at the upper lumbar level, it is also recommended to carefully examine whether the exiting nerve root is traveling too vertically.

3.3 Needle Insertion and Optimal Trajectory of Approach

The needle insertion process is the starting point of effective and safe entry route creation. The initial trajectory is established during the skin entry point determination and needle and obturator insertion process. The approach trajectory is made by selecting the target, determining the starting point of entry, and setting the angle of entry. Optimal Trajectory can be said to be the safest and closest approach from the starting point to the target point through a path that avoids damage to normal structures in the correct direction and at an appropriate angle.

TELD is a method of approach starting from the dorsolateral toward the medioventral. Usually, the lower lumbar level approaches at an angle of about 25–30 degrees from the horizontal plane, and when approaching the upper lumbar level or the foraminal zone, it approaches at a larger angle. However, it does not enter by deliberately setting a fixed angle. In the process of determining the target point and the skin entry point described above, an appropriate entry angle is naturally determined automatically. An appropriate trajectory corresponding to the line connecting the target point and the good entry point is also made in this process. In the upper and lower lumbar regions, the triangular safe zone has a slightly different triangular shape depending on the travel angle of the exiting nerve root corresponding to the hypotenuse. Depending on the level, the lamina width, the size and orientation of the facet, and the width of the dura are also slightly different (Fig. 12). If the skin entry point is determined as a line passing through the facet ventral or ventrolateral surface from the initial primary target point (a point close to the HDF and MPL and located above the annular surface of the triangular safe zone) as described above, the angle of entry at the upper lumbar level is more vertical than at the lower lumbar level (Fig. 13).

The entry angle needs to be determined with respect to the coronal plane as well as the angle determined from the axial plane. This is due to the characteristics of TELD entering from the dorsolateral side. If an interlaminar approach with a posterior approach near the midline is performed, the angle of the sagittal plane reference should be well determined. The approach angle of this coronal plane reference is determined by the skin entry point No. 3 process described above (Fig. 22b, c). This can be expressed as cranio-caudally inclined or oblique trajectory [42, 45].

After entering the endoscope, many changes can be made from the initial angle of entry through levering. The initial approach angle is not an absolute value.

Accurate aiming toward the target requires a three-dimensional sense of space. Implementation of an appropriate approach trajectory, including the approach angle and orientation, will gradually become familiar to the surgeon in the learning curve. At the beginning of the learning curve, it is very helpful to try many transforaminal blocks in the same route as the endoscope entry. In addition, drawing many landmark lines such as midline, medial pedicular line, measured skin entry line, and posterior vertebral line using c-arm fluoroscopy is very helpful for targeting.

During the needle insertion process, local anesthesia, epidurogram, and discography are performed along with initial targeting and creating access. An 18-gauge long needle rather than a fine needle is good for targeting and handling and is commonly used. Lidocaine is mainly used as a local anesthetic, and it is recommended to inject a sufficient amount into the subcutaneous tissue and epidural space. Epidurogram confirms the safe triangular zone of the foramen area (Fig. 23a). Discography is used to identify the annular defect site and the degree of degeneration of the disc. When a mixture of radio-opaque dye and indigo carmine is injected, loose and flabby discs are dyed blue. When indigo carmine passes through the annular hole, the surrounding area is slightly stained, but most of the herniated disc fragments that are stuck in a narrow space are not stained. If only the blue disc fragments have been removed, it is highly likely that the herniated disc fragments, the main cause of symptoms, have not yet been removed. Injecting too much volume with excessive pressure during discogram may cause unnecessary severe pain and, in rare cases, may cause migration of fragments of the herniated disc, so caution is required [84].

3.4 Obturator Insertion Technique and Annulus Entry Point

During the initial access process, proper use and handling of the obturator (tapered blunt dilator) is very important. Even slightly misaligned needle insertion is corrected through this blunt tapered dilator. The two most important tools that require the best handling during the TELD procedure are the obturator and forceps. The

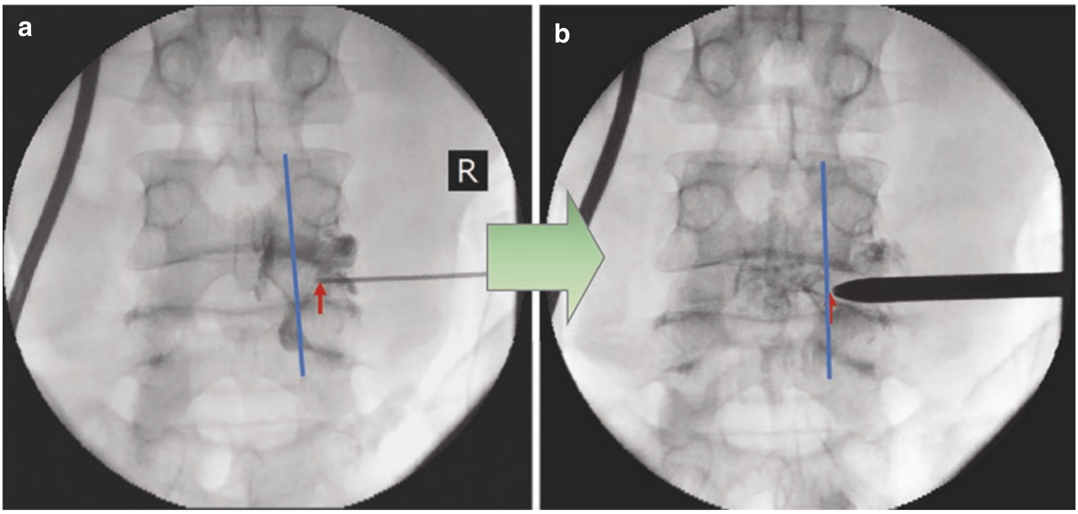


Fig. 23 Needle and obturator insertion. It is ideal for the needle to enter the mid to medial pedicular line (**a**) and the obturator to the medial pedicular line (**b**)

obturator is the rod of the dilating device, and it enters between the skin, subcutaneous tissue, fascia, and muscles to create an access path for the working tube. It also plays a useful role in entering the disc through the annulus fibrosus. The obturator is easier to control at the distal end than a needle that can be bent in an undesirable direction, and it is relatively safe because it has a blunt end (Fig. 25a). Optimal trajectory is initially set mainly by needle insertion, and the handling of the obturator can correct and adjust this trajectory to get closer to the target point and MPL (Fig. 23b).

Other tools for creating an entry track and passing the annulus through it include serial sequential dilating tubes, round annulotomes, and serrated trephines. However, using a tapered obturator with a blunt distal end rather than using them has many advantages in terms of shortening the entry time, shortening the patient's pain period, safety, and occurrence of small annular defects.

The initial surgical procedure of TELD proceeds in the following order: needle insertion, guide wire passing through it, needle removal, obturator insertion through the remaining guide wire, and railroading working cannula over the obturator. There is an important step to add between these processes. That is to remove the guide wire after inserting the obturator. It is effective to remove the guide wire that entered through the needle, handle the obturator free to move, position it closer to the target, and determine the annulus entry point. The annulus entry point for working cannula installation is determined when the obturator enters, and this point may be different from the annulus entry point of the needle for discogram. It is ideal for the needle to enter the mid to medial pedicular line and the obturator to the medial pedicular line (Fig. 23). Since the dura and traversing root are dislocated in the dorsal direction by the herniated disc, it is usually safe to access the needle to the medial pedicular line. However, a close approach using a blunt obturator reduces the chance of dural injury.

When performing TELD for intracanal disc herniation, it is necessary to approach the obturator as close as possible to the MPL, and it is also recommended to perform the annulus entry point at this position (Fig. 24). The point at which the obturator passes through the annulus has the greatest influence on the success of all the steps of the procedure to remove herniated disc fragments. Depending on the difference in the lateral distance of about 5 mm between the mid-pedicular line and the medial pedicular line, the procedure may become easier or more difficult. As described in the accessible range of the endo-

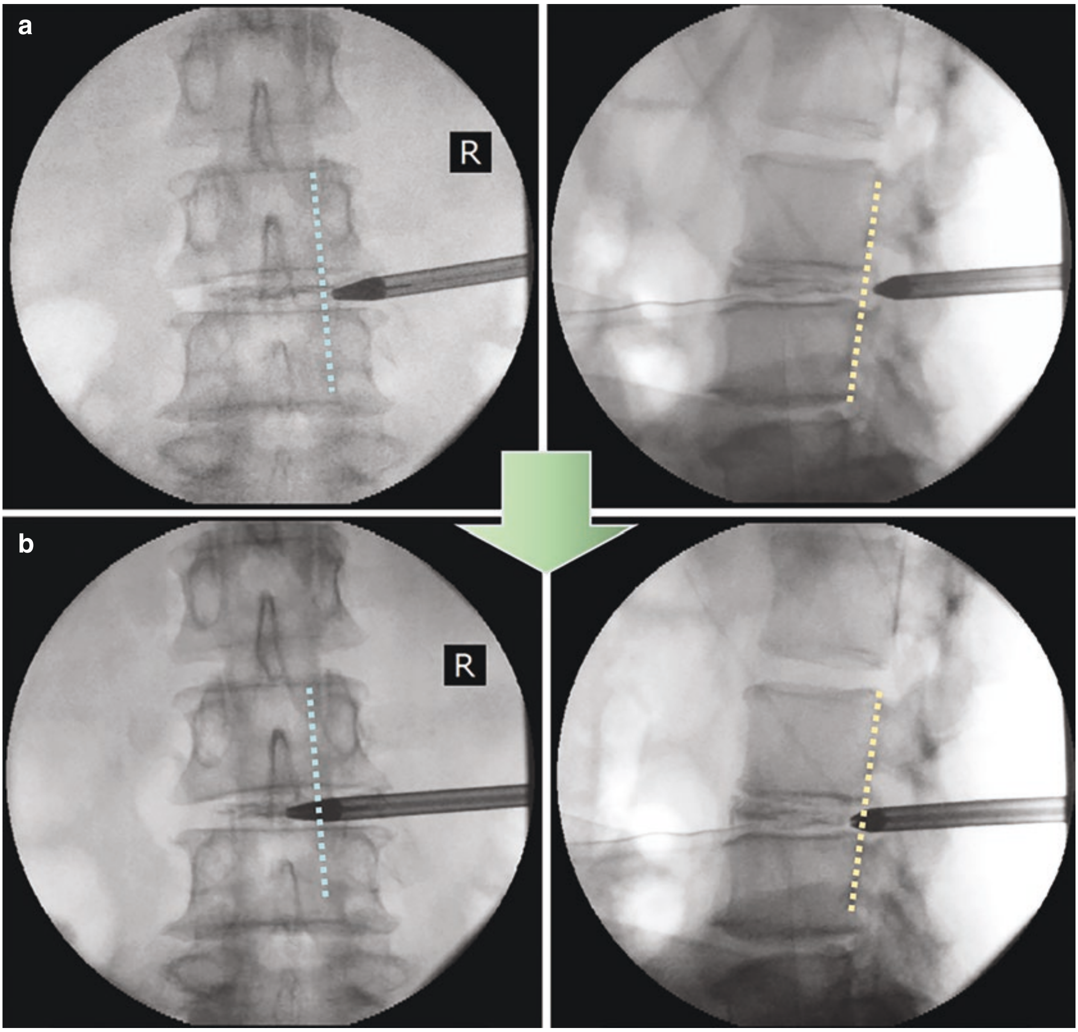


Fig. 24 Obturator insertion technique and annulus entry point. The blunt tapered obturator allows safe selection of the annulus entry point as close to the medial pedicular line (MPL) as possible. After approaching as close to the MPL as possible along with the dissection motion (**a**), it is necessary to apply force toward the ventral when tapping and entering (**b**)

scopic forceps, when approaching at an angle of 30 degrees, the distal end of the endoscope moves away from the dorsal side where the target is located by about 3 mm for every 5 mm of the lateral distance as the endoscope enters (Figs. 8 and 10). Considering the length of the usual forceps actuating jaw 7 mm, the difference depending on whether the annulus entry point is the medial pedicular line or the mid-pedicular line is not a small difference (Fig. 11). Not only accurate trajectory access, but also the proper annulus entry point set by the obturator is a very important factor in getting the endoscope close to the ultimate target area so that the endoscopic forceps can grab the herniated disc fragments. It can be said that the most crucial step of the access is handling of the dilating obturator.

When the obturator is introduced from the MPL, the beveled opening of the working cannula is more likely to seat directly or very close to the annular defect site (Fig. 28a). The ideal obturator entry is by splitting the annulus fibrosus near the defect site of the annulus. During proper obturator handling, it slides between the annular fissures or into the annular defect area, thereby reducing further damage to the annulus fibrosus.

Depending on the position of the lateral margin of the dura, the annulus entry point can be slightly different. Depending on whether the index level is at the upper lumbar level or the lower level, and depending on how the herniated disc dislocates the lateral margin of dura, the annulus entry point may be slightly changed. However, in any case, it is recommended to select the annulus entry point as close to the MPL as possible within the range to avoid dura and nerve injury during TELD for intracanal disc herniation.

As a safety tip when entering the obturator, giving a dissection effect through shaking motion in the craniocaudal direction on the medial pedicular line helps to prevent dura injury. In order not to shock the nerve, it is also a trick to enter the obturator by tapping it while applying force to the ventral when it passes through the annulus.

As mentioned above, there are cases in which annular puncture is not performed with an obturator at the beginning of the procedure. These include using outside-in tactic for performing foraminoplasty first, or cases of very severe huge central disc herniation. In these cases, rather than using the obturator again, it is better to make a small gap in the annulus with a small scalpel or laser through the endoscopic field of view and advance the working cannula further after partial decompression.

3.5 Proper Working Cannula Placement

The placement of the working cannula is an important step that affects the success of the procedure. Improper placement of the working cannula results in herniated disc fragments out of reach of the endoscopic forceps and may lead to failure of the procedure [57].

The distal end of the working cannula, which serves to secure the working space of the endoscope, has various shapes. It can be divided into beveled type and round type, and the beveled type has several different shapes depending on the cut angle and shape of the bevel face (Fig. 25c, d). It is necessary to select an appropriate cannula according to the shape of the workspace so that soft tissues such as blood vessels and fat do not block the field of view in the endoscope workspace. A round-end working cannula is relatively useful for vertical access and straightforward procedures, such as in the interlaminar approach or in the treatment of extraforaminal disc herniation. However, the beveled type is usually more useful in a transforaminal approach that requires access to the tissues on the upper or lateral side of the endoscopic workspace. Among the bevel-type working cannulas, a cannula with an elliptical face with a long bevel (Fig. 25d) secures a wide working space, reduces damage to the annulus or surrounding endplate when entering subannular space, and has advantages such as effective entry into narrow spaces. Referring to several anatomical studies related to the dimension of the triangular safe zone and the safe canal diameter, it may be safe to use tools with a small diameter of about 6–8 mm or less [18, 19]. However, the blunt tapered obturator and the long-beveled cannula of the oval face overcome these limitations to some extent due to the characteristics of expanding the space during the entry process. Proper entry and proper positioning of these tools have the effect of safely increasing the actual safe working zone.

Correct placement and proper anchoring of the working cannula in a good location will greatly facilitate successful procedures. Proper placement means placing it in a location that is safe and as close as possible to the target working point. It is recommended to select a target working point that can be performed together with removal of the herniated disc compressing the nerve and decompression of the subannular space around the base of herniation. Decompression around the base of the herniated disc is also necessary to prevent residual back pain and recurrence, but it is reasonable to give priority to fragmentectomy, which eliminates the main cause of symptoms. Therefore, close access to the annular defect site where the herniated disc occurred or direct access to the annular defect

Fig. 25 Endoscopic instruments. (**a**) Obturators (dilators with blunt tapered ends). (**b**) Sequential dilating tubes. (**c**, **d**) Various types of work cannulas

site is an ideal approach. In the case of TELD treatment for the foraminal and extraforaminal zones, the angle of entry is more vertical and it is a partially transforaminal procedure. However, in the case of intracanal disc herniation located in the central and subarticular zone, which is a more common herniated disc clinically, it is recommended and necessary to implement a transforaminal approach that completely passes through the intervertebral foramen.

Basically, the ideal placement of the beveled working cannula is such that the inclined elliptical bevel face of the working cannula is positioned at the base of the herniated disc. It would be most appropriate to secure the prolapsed disc into the epidural space, the annular defect site where the herniated disc occurred, and the subannular space in the working space. On the C-arm fluoroscopic view, it is recommended that the bevel face providing the workspace be placed half and half on the ventral and dorsal side with respect to the posterior vertebral line in the true lateral view. At this time, in the anteroposterior view, the distal end of the working cannula should be positioned at or close to the midline (Fig. 26). This can be called Medial Half-and-Half technique.

If the bevel faces are located half-and-half in the lateral view and the distal end of the working cannula in the anteroposterior view is located on the lateral side far from the midline, the probabil-

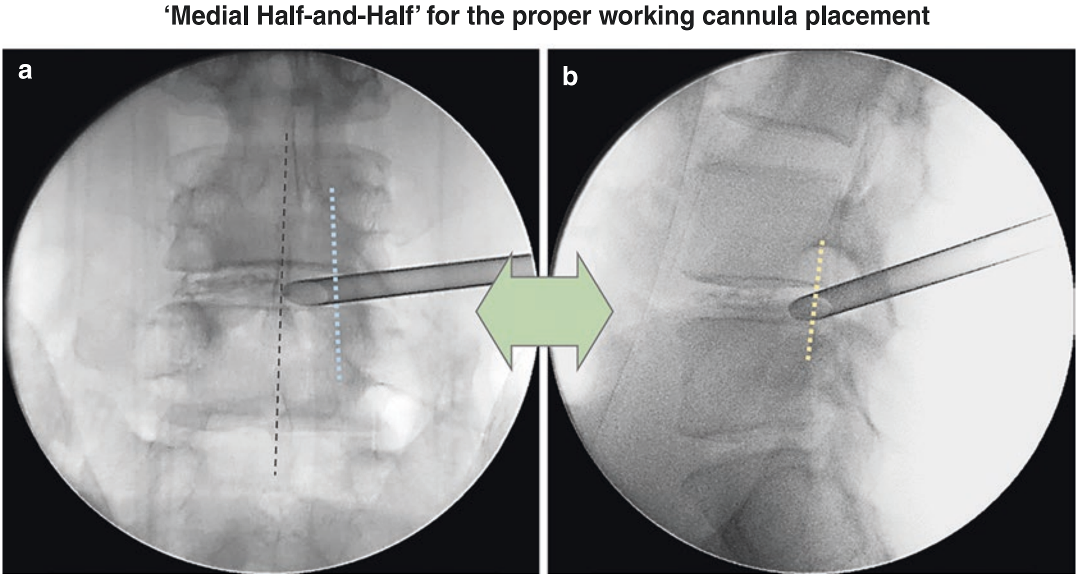


Fig. 26 Ideal working cannula placement in TELD for intracanal lumbar disc herniation. (**b**) On the C-arm fluoroscopic view, it is recommended that the bevel face providing the workspace be placed half and half on the ventral and dorsal side with respect to the posterior vertebral line (yellow dotted line) in the true lateral view. (**a**) At this time, in the AP view, the distal end of the working cannula should be positioned at or near the midline (black dotted line) so that the working cannula bevel face is on the medial side of the MPL (sky blue dotted line)

ity of failure of the procedure increases (Fig. 33f). Also, when it is located near the midline in the anteroposterior view and all the bevel faces are located inside the disc in the lateral view, the probability of failure is similarly increased. In these cases, it may be necessary to reset the approach angle or reposition the working cannula after foraminoplasty (Fig. 33g). Also, as described above, as the annulus entry point of the working cannula moves away from this midline, the useful available reach of the actuating jaw of endoscopic forceps toward the dorsal side where the prolapsed disc is located decreases due to the effect of the angle of entry (Fig. 10).

When levering of the working cannula is required in the dorsal direction where the prolapse disc is located, the point serving as the axis of the lever is the surface of the annulus underneath the working cannula. If this point is on the lateral side, the position of the lever axis is lowered due to the round disc surface structure, so that the levering effect cannot be exerted much. The starting point of entry into the annulus of the working cannula is as close as possible to the MPL.

It is recommended to start decompression around the herniated disc at the beginning of the procedure and gradually rotate the bevel of the working cannula to face the herniated disc fragments. After placing the working cannula at this ideal position during the initial approach, the position can be gradually changed as needed as the work progresses. In TELD for highly migrated disc herniation, after initial decompression in the subannular space from the initial working cannula position, it may be necessary to retreat the working cannula and mount the working cannula to the secondary position through the foraminoplasty procedure. In the case of highly up-migrated disc herniation, it may be necessary to override the working cannula on the dorsal surface of the vertebral body (Fig. 27c). In cases of highly down-migrated disc herniation, it may be necessary to mount it on the ventromedial surface of superior vertebral notch (Fig. 27d).

The appropriate placement of the working cannula at the beginning of the procedure may be changed to other positions. If the foraminoplasty is required due to the narrow foraminal dimen-

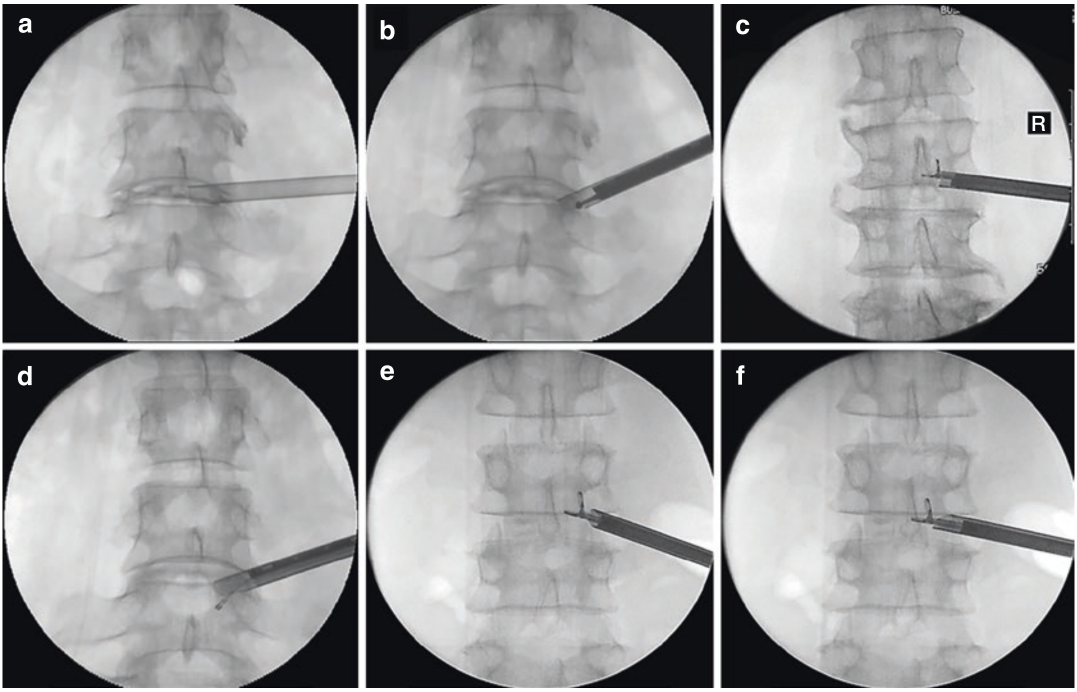


Fig. 27 Change of working cannula position from the primary position to the final position toward the target. After initial decompression in the subannular space from the initial working cannula position (**a**), the working cannula position can be changed (**c**–**f**) through the foraminoplasty process (**b**) according to the direction of the herniated disc. (**c**) A mounted working cannula overriding the vertebral body dorsal surface. (**d**) A mounted working cannula overriding the ventromedial surface of the superior vertebral notch

sion, the initial primary anchorage position of the working cannula can be set to the ventrolateral surface of the superior articular process. In most cases of TELD procedure for L5-S1 level, the working cannula is placed in this position at the initial stage, and the entry proceeds after foraminoplasty. Even at L5-S1 level, it is desirable that the annulus entry point be as close to the MPL as possible, but it is not necessary to enter deep into the midline to check the medial half-and-half positioning of the working cannula as described above. The reason is that during TELD in L5-S1, the influence of the angle of entry in the rostrocaudal direction can cause damage to the S1 upper endplate when entering deeply. In cases where it is judged that it is necessary to gradually enter the inside after partial decompression from the outside of the disc in an extremely large volume of herniated disc, the primary position of the working cannula can be the surface of the annulus outside the disc. Also, when planning an outside to in tactic in which first removing the ruptured disc fragments, and then proceeding to the subannular space in the TELD for disc herniations that cause extreme pain, the initial positioning of the working cannula may be set in the space around the junction of the disc surface and vertebral body close to the herniated disc fragments (Fig. 27e).

3.6 Full-Visualized Endoscopic Procedure

Although there are slight differences, the endoscopes used for TELD have an outer diameter of about 6–8 mm and a working channel of about 3–4 mm inside. Considering several anatomical studies, these diameters of endoscopes used in the transforaminal approach are more safe and effective [18, 19]. The distal end of the endoscope has a slope structure, and the lens that faces upward at an optical angle of about 25 to 30 degrees is located on the lowest side, and the working channel is located at the top, and it has small irrigation channels on both sides.

Because the working portal is not located in the center, the endoscopic forceps passing through it may approach or move away from the target through rotation of the endoscope.

After the stage where the endoscope can be entered through the working tube, it is recommended not to use tools under fluoroscopic guidance, and all possible procedures should be performed in the endoscopic field of view (Fig. 28). Reckless work that can cause nerve damage in the unseen field of view should be avoided. Instruments in the field of spinal endoscopy have been developed a lot compared to the past and are also gradually developing with the expansion of indications. The diameter of the working channel of the endoscope became diversified and enlarged, and the endoscopic forceps also became thicker and longer to improve the grasp power. The endoscope drill has also improved its function, and with the development of the electric endoscope drill, it is very stable and shows high power (Fig. 28e). With the development of instruments passing through the endoscope, the necessity of using tools such as C-arm-guided large forceps, reamers, and manual drills used under fluoroscopic guidance is disappearing.

A simple expression of a successful endoscopic procedure is to reach the target, see it well, and remove it. Securing a clear endoscopic field of view can affect successful procedures and is closely related to safety. In order to secure a clear endoscopic field of view, it is necessary to clean the tattered soft tissues surrounding the endoscopic workspace using radio frequency cautery and laser, and to expand the field of view through foraminoplasty and remove obstacles that block the field of view. Blurred vision may be a problem with the lens or optical cable, but bleeding is the most common cause. In the case of bleeding, it is recommended not to proceed with the procedure in a bad field of vision, but to proceed with the procedure after securing a clear field of view through faithful hemostasis.

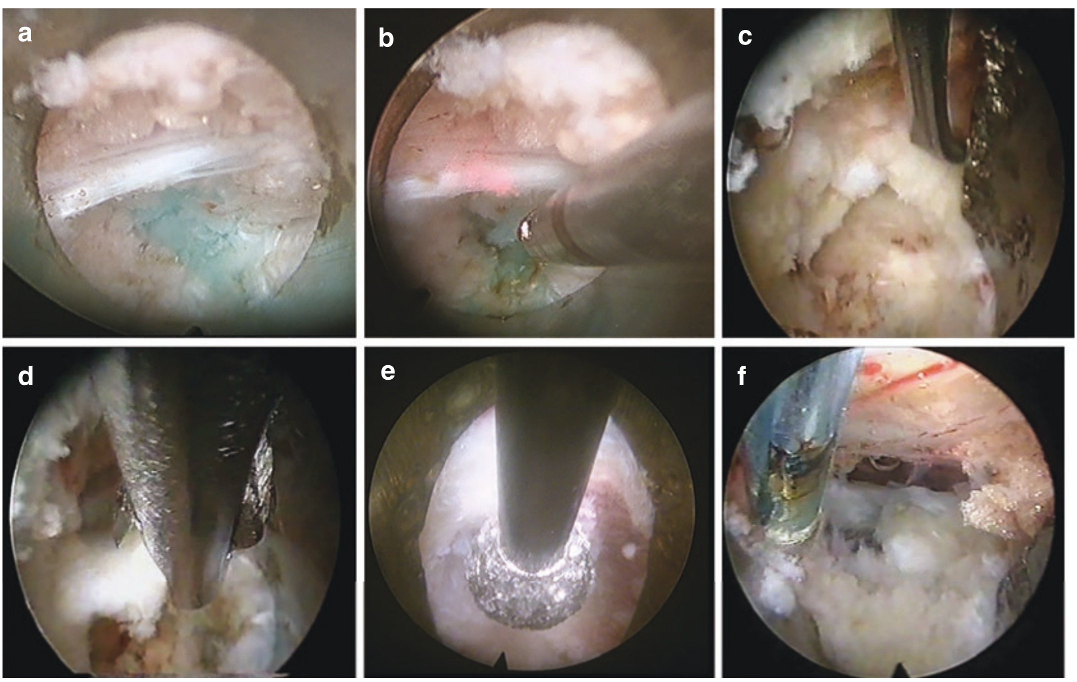


Fig. 28 Full-visualized endoscopic procedure. Securing a clear endoscopic field of view (**a**–**f**) can affect successful procedures and is closely related to safety

3.7 Foraminoplasty

The procedure of foraminoplasty can be performed when necessary during the procedure, or it can be performed under a plan at the beginning of the procedure. Foraminoplasty facilitates the TELD to be performed completely through the intervertebral foramen, and serves as an important solution for increasing the accessible range of endoscopic forceps. The foraminoplasty plays a role in removing obstacles in the approach trajectory to reach the target point and expanding the entry window.

TELD is usually performed in a prone position and is a method of approaching the target from the superolateral point. Foraminoplasty is a work that raises the eaves (inferior surface of superior articular process) and widens the window (intervertebral foramen) to ensure effective entry into the problem space and easy retrieval of objects (herniated disc fragments) located in the wrong space (epidural space).

The following cases, which are indications for foraminoplasty, usually require foraminoplasty for effective TELD. First, central disc herniations in which the initial primary target point cannot be set close to the medial pedicular: These are cases where it is not easy to access close to the medial pedicular line for intracanal access due to hypertrophied facet, narrow foramen due to disc height loss, horizontal oriented wide facet, and central zone disc herniation at L5-S1. Second, sequestrated disc herniations migrated beyond the disc level: Foraminoplasty is usually required if the dislocated herniated disc is not located at the disc level and there is no continuity with the parent disc (Fig. 35). Third, highly migrated disc herniations in which the center of the herniated disc fragment is more than 7 mm away from the endplate level: Considering the anatomical structure and dimensions of the intervertebral foramen and the characteristics of endoscopic instruments, further migration is very difficult to resolve without foraminoplasty. In addition, foraminoplasty can be used as a treatment for foraminal stenosis.

Foraminoplasty in TELD can be performed before entering the target disc after anchoring the working cannula to the facet ventral surface under planning at the beginning of the procedure. Alternatively, after entering the working cannula into the subannular space, internal decompression of the base of the herniated disc is followed by retreat back to perform foraminoplasty. If the foraminal dimension is relatively wide and the obturator can be entered near the MPL, it is better to try herniated disc removal through annular release in the subannular space and then retreat back if necessary to perform foraminoplasty. If the obturator cannot initially approach the MPL, it is recommended to anchor the working cannula below the ventrolateral surface of the superior articular process and perform foraminoplasty first.

The required amount of foraminoplasty may vary depending on the location and direction of the herniated disc and the level of occurrence. There is a light foraminoplasty that removes only the soft tissues around the foramen such as foraminal ligament or yellow ligament without bone work, and there is an extended foraminoplasty that removes the bony structures. For light foraminoplasty, where only soft tissue is removed, endoscopic forceps, endoscopic punches, and electrosurgical tools are usually used. Ablation of the foraminal ligament using flexible RF cautery and side-firing holmium:yttrium-aluminum-garnet (Ho:YAG) laser is a very useful method (Fig. 29). In the case of extended foraminoplasty requiring bone work, an endoscopic drill is an essential tool (Figs. 28e and 29a), and an endoscopic shaver, endoscopic shaft (endo-kerrison) punch and endoscopic chisel can also be used. Manual drills, bone trephines, and reamers were frequently used in the past, but with the development of endoscopic high-speed electric drills, the need for these fluoroscopically guided tools has almost disappeared.

At the upper lumbar level, it is relatively easy to access the epidural space outside the annulus, and there are many cases where TELD treatment for migrated disc herniation can be performed using a light foraminoplasty or without the need for foraminoplasty. Foraminoplasty at the L4-5 and L5-S1 level of the lower lumbar region often requires bone work.

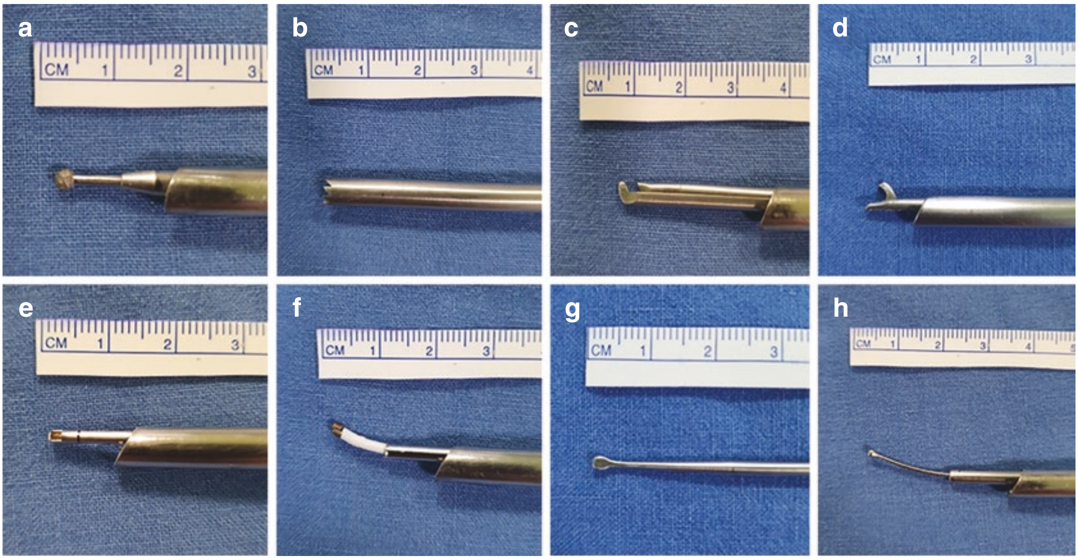


Fig. 29 Mechanical and electrosurgical instruments. (**a**) Endoscopic drill. (**b**) Reamer. (**c**) Endoscopic shaft (endo-kerrison) punch. (**d**) Endoscopic cutting rongeur. (**e**) Laser. (**f**) Flexible radio frequency (RF) probe. (**g**, **h**) Endoscopic dissector & probe

The main site of foraminoplasty is usually a ventral part of the superior articular process of the lower vertebra and the foraminal ligaments beneath it. For caudally migrated disc herniation, the process of widening the medial portion of the superior vertebral notch is additionally performed. The superior vertebral notch consists of the ventrocaudal part of the superior articular process, the upper surface of the pedicle, and the dorsal surface of the vertebral body around the endplate. Their medial area can be selected as the site for foraminoplasty in TELD for caudally migrated disc herniation. In the case of cranially migrated disc herniation, along with the ventral surface of the superior articular process, the lamina lateral part below the pars can be additionally shaved if necessary. In most cases of highly down-migrated disc herniation, foraminoplasty with bone work is often required. Herniated discs in the highly up-migrated central zone often require bone work and sometimes require the working cannula to partially override the dorsal surface of the vertebral body. However, as most of the herniated discs in the cranial direction are located laterally below the pars, it is sufficient for foraminoplasty of soft tissue removal and bone work is not required in many cases.

Foraminoplasty is recommended to be performed as little as necessary, and to avoid damaging the facet joints or destroying the stability of the spine due to excessive violation, and also pay attention to postoperative hematoma.

3.8 Levering

In TELD using a rigid scope, adequate levering of the endoscopes plays a role in extending the boundaries of the endoscope forceps along with rotation of the endoscopes in the workspace. The working cannula approached through a long track is difficult to translate, but relatively easy to move using a lever action. Levering is not a special technique, but a movement that is used naturally during the procedure. It allows instruments that have passed through the working channel of the endoscope to get closer to the target point. Effective use of levering and foraminoplasty can be a method to increase the reach of endoscopic forceps and facilitate access to the epidural space.

If the working tube becomes too flat due to excessive levering or the part acting as the axis of the lever is lowered, exiting nerve injury may occur. When levering the endoscope, the axis is mainly played by the annular entry point of the working tube. Due to the round disc surface, the levering effect decreases as this axis moves away from the midline. The closer the annular puncture point is to the MPL, the higher the effect of levering movement and the lower the possibility that the exiting nerve will be compressed. The width between the superior articular process and the exiting nerve root corresponding to the hypotenuse of the triangular safe zone usually decreases from the lower lumbar level to the upper lumbar level [20]. If the width of the triangular safe zone is narrow due to the vertical travel of the exiting nerve root, it is necessary to be careful about the possibility of an exiting nerve injury caused by levering of the endoscope. It should be noted that, when levering excessively with excessive force, the procedure may not proceed smoothly due to bending or damage of the endoscope.

3.9 Procedure of Discectomy (Subannular Space Decompression, Annular Releasing, and Fragmentectomy)

Although removal of the herniated disc fragment compressing the nerve is the top priority, it is better to remove loose fragments (cracked and separated disc particles) in the intradiscal space around the base of the herniated disc to prevent residual pain or reherniation after the procedure. The principle of avoiding extensive removal of excessive amounts, preserving the normal disc, and minimizing the annulus fibrous defect is the same as that of open lumbar microdiscectomy.

3.9.1 Decompression of Subannular Space Around the Base of Herniation

Subannular space decompression means work to prepare free space for the prolapsed disc to descend under the annulus, and it is also a process to prevent recurrence and residual symptoms. This proceeds with the process of decompressing the area surrounding the prolapsed main disc mass, shrinking the loose disc material, and removing the separated disc particles that are concerned about recurrence. In general, it is usually performed at the beginning of the procedure. However, in the case of severe sequestrated disc herniation, it can be performed as a finishing operation after fragmentectomy by planning outside to in tactic. If an annulus defect or Modic change is significant, it is necessary to perform more meticulously. Considering the direction of entry of the endoscope, it is recommended to pay special attention to the surgeon side intradiscal loose fragment. Efforts should be made to preserve the normal disc as much as possible, and it is better not to remove the central and ventral side other than the subannular space.

3.9.2 Annular Releasing

Annular releasing is a procedure that prepares a pathway for retrieval. Reminiscent of the safe stealing method in the movie The Italian Job, it will be helpful for an interesting understanding of annular releasing. Annular releasing is a process that loosens and widens the annular fissure at the bottom of the prolapsed disc to facilitate removal.

In cases of contained disc herniation, annular releasing is not required. However, symptomatic patients who require treatment often have uncontained disc herniation. Among the cases of uncontained disc herniation, if the annular defect is large or the prolapsed disc is not tightly squeezed between the annular fissures, annular releasing is often unnecessary. Annular releasing is also not required when the working tube is directly inserted into the annular defect site. Annular releasing is usually necessary in uncontained disc herniation when the herniated disc fragment is not connected to the parent disc or is tightly entrapped at the opening site of the anulus. Endoscopic forceps, endoscopic cutting rongeur, and side-firing laser can be used as tools for annular releasing (Fig. 29c, d).

The annular defect site where the herniated disc occurs is most often close to the midline. It is recommended to perform annular releasing for retrieval of herniated disc fragments using the existing annulus fibrous defect on the medial side rather than from the side. Even if the herniated disc is not connected to the parent disc at the opening of the annulus fibrosus, annular releasing would be performed in the annular defect area near the midline around the bottom of the herniated disc. However, if this is not possible, it could be performed from the side where the working cannula entered. In TELD for highly migrated disc herniation, there is a high probability that disc fragments are not removed using only the annular defect site where the disc herniation occurred. In these cases, if necessary, annular releasing may be performed from the side. Adequate annular releasing along with foraminoplasty facilitates entry of the endoscopic forceps toward the migrated disc fragments.

It is recommended to perform annular releasing as small as possible for annular competence. Annular releasing may include posterior longitudinal ligament resection, but it is better to preserve it as much as possible. After retrieval of the herniated disc, it is recommended to shrink the annular defect area through the RF coagulator to prevent recurrence, back pain, and possible ventral herniation of the dura and nerve root.

3.9.3 Fragmentectomy

In order to successfully remove the herniated disc fragment and prevent missing or remaining fragments, sufficient work around the target disc fragments should be performed to ensure a clear view and free space for the herniated disc to be retrieved. After entering the endoscope, it is recommended to perform the decompression procedure from the side away from the fragment without rushing toward the fragment. Appropriate annular releasing and decompression of the area surrounding the herniated discs facilitate complete removal of the HDF.

Above all, the most important tool that plays a conclusive role in endoscopic work is endoscopic forceps. Effective use of endoscopic forceps is very important for successful removal of the herniated disc fragments. There are many different types of forceps, and these forceps can be purchased through the manufacturer or can be specially made (Fig. 6). The endoscopic forceps consists of a long shaft passing through the working channel of the endoscope and jaws at the distal end. According to the function of the jaws, it can be divided into double action forceps and crocodile action forceps. In the case of a vertical approach, such as when using an interlaminar approach or to remove a foraminal or extraforaminal disc fragment with a transforaminal approach, sometimes bidirectional double-action forceps approach closer than crocodile action forceps and catch the prolapsed disc fragment (Fig. 6b). However, in usual TELD for the treatment of intracanal disc herniation, crocodile action forceps composed of a stationary jaw and an actuating jaw are useful in most cases due to the characteristic approaching from the lateral to the center (Fig. 6a). For the fragmentectomy in the final procedure, the use of thick forceps is not recommended as it blocks the field of view of the optic lens located below the working channel. It is good to use forceps capable of fine work that have the longest reachable length within the limit that does not deviate from the endoscopic field of view. In general, 7–8 mm long endoscopic forceps with a default open angle of 90 degrees is best (Fig. 7a).

It is necessary to approach so that the working cannula is positioned within the boundary of the actuating jaw of the endoscopic forceps to reach the center of the prolapsed disc fragment, not just the tail or tip. If the herniated disc fragment is properly gripped with endoscopic forceps, it is better to induce it to come out gradually toward the exit rather than to pull it out quickly. Repeating grabbing, rolling and pulling motions rather than simply pulling is helpful in preventing missing disc fragments.

Since the prolapsed fragments are cracked masses, it is necessary to perform the procedure with suspicion of the possibility that they are multiple disc fragments rather than a single mass. As mentioned earlier, indigo carmine injected with the discogram at the beginning of the procedure cannot stain the main mass of the extruded disc stuck in the compressed space in most cases. If the removed disc mass is heavily soaked in indigo carmine, it should be noted that the mass is not the main pathologic herniated disc mass. It is helpful to prevent residual disc by comparing the volume of the removed fragment with the MRI findings before the procedure. In addition to checking the decompression by probing tools, it is very helpful to perform a grasping motion several times through the entry of the endoscopic forceps into the location of the prolapsed disc fragment, to ensure complete decompression and to prevent remaining fragments. At this time, it is necessary to confirm the position of the endoscopic forceps in fluoroscopy (Fig. 20).

3.10 Confirmation of Decompression

Confirmation of decompression is helpful with probing to confirm the smooth entry of a flexible bipolar probe and opened actuating jaw of forceps into the epidural space without resistance. It is best to check the epidural space and nerve root decompression in the endoscopic field of view (Figs. 28f and 30). Reckless additional foraminoplasty or excessive annulus removal just to check for decompression would be undesirable. Using a flexible bipolar probe or opened actuating jaw of forceps to gently lift the dura and nerve root to check the epidural space in the endoscopic field of view and to check their location with a fluoroscopy image is a very useful method to confirm decompression (Figs. 20 and 27d). Pressure control of the irrigation fluid and the Valsalva maneuver such as coughing of the patient are also helpful in confirming residual disc and decompression. Before the procedure is finished, active hip lifting and kicking motions of the patient are useful tips to confirm the decompression as well as the presence of intradiscal loose fragments. Final confirmation is postoperative MRI. It is recommended that confirmatory MRI be performed immediately without omitting or delaying.

3.11 Hemostasis and Closing

In endoscopic surgery, hemostasis is essential not only for closing, but also for smooth operation. This is because if there is bleeding, it causes blurring of the field of vision to make it difficult to proceed with TELD. The best method of hemostasis in case of bleeding is to temporarily increase the irrigation speed to secure the field of view and to use the RF coagulator after finding the bleeding site. Bleeding is usually controlled with the help of this flexible bipolar radio frequency cautery. If this method does not solve the problem with input fluid enough to cause an increase in intracranial pressure, it may be necessary to insert a hemostatic agent into the field and wait for a while after inserting the obturator. Alternatively, one of the methods is to enter the endoscope into the disc to prevent bleeding from entering the endoscope's field of view and perform the necessary steps and then perform the hemostasis again later.

If hemostasis is not complete and seeping bleeding is significant at the last stage of the procedure, or if there is concern about bone bleeding

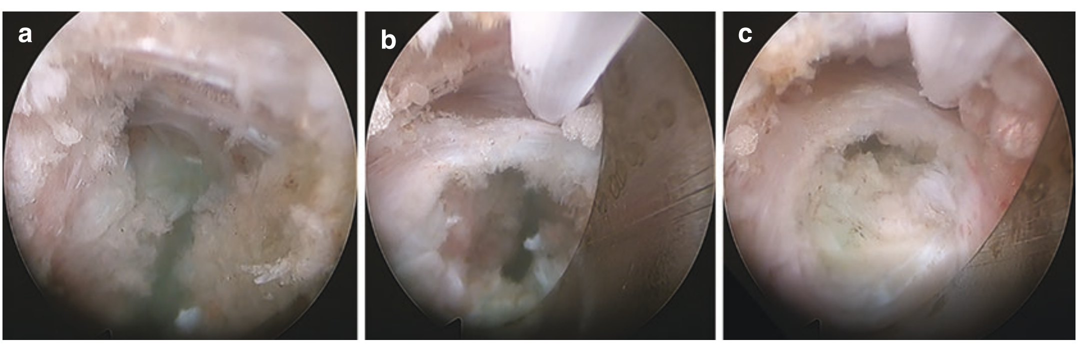


Fig. 30 Process of confirming the decompression (**a**), probing (**b**), and shrinkage of the annulus (**c**)

due to a lot of bone work, it is better to insert the drain tube without hesitation before removing the working tube.

After the hemostatic procedure and removal of the working cannula with an endoscope, the skin is usually closed with a subcutaneous suture and sterile adhesive tapes.

4 Postoperative Consideration

Because the procedure is performed under local anesthesia, evaluation of the patient's symptoms and neurological and physical examination can be performed immediately after the procedure. In some cases, temporary loss of sensation and muscle strength may be seen under the influence of epidural anesthesia. Therefore, it is recommended to avoid long-acting local anesthetics to avoid confusion with postoperative complications.

It is recommended to check the MRI immediately after the procedure to confirm the radiological findings. If there are residual disc findings after the procedure and there is no recovery or worsening of muscle strength, an additional endoscopic procedure or open surgery is recommended immediately rather than follow-up.

If the drain tube has been inserted, it can be removed after maintaining it for about 3 to 4 h. Usually, patients are discharged from the hospital after checking the progress of symptoms for 6 to 12 h.

Upon discharge, it re-educates that disc herniation is a disease that can recur, and emphasizes the importance of maintaining the lumbar lordotic curvature during the healing period of about 2–3 weeks. Follow-up visits after the procedure are usually performed 3 to 4 weeks, 3 months, 6 months, and 1 year after the procedure. It is recommended to check the T2-weighted MRI at 1 year after the procedure to evaluate whether the management was successful without recurrence and to evaluate the procedure. For long-term follow-up, a visit may be recommended for 2 or 3 years or more after the procedure.

5 Case Illustration

5.1 Case 1. (TELD for Subarticular Zone Disc Herniation)

A 31-year-old female patient visited our hospital with a cane complaining of severe right lower extremity radiating pain. The VAS score was 9, and the motor power of ankle plantar flexion was grade II–III with straight leg raising (SLR) test positive at <30°. Preoperative MRI showed severe soft disc herniation at L5-S1 subarticular zone. TELD was performed under local anesthesia with intravenous sedatives. Postoperative MRI showed complete herniated disc removal and full decompression. Her pain was alleviated by a visual analogue scale (VAS) score of 1, and she showed a rapid recovery of muscle strength. She was discharged the day after the procedure without any special sequelae (Fig. 31).

5.2 Case 2 (TELD for Central Zone Disc Herniation)

A 30-year-old female patient presented with right leg radiating pain. The visual analogue scale (VAS) score was 8, and the motor grade in the right ankle was III–IV. MRI showed huge central disc herniation at the L4–5 level. TELD was performed under local anesthesia. Successful removal of herniated disc was achieved, and her symptoms recovered immediately after the procedure (Fig. 32).

5.3 Case 3 (TELD for Central Zone Disc Herniation, Improper Working Cannula Placement)

A 32-year-old female patient presented with left leg radiating pain. The visual analogue scale (VAS) score was 6, and the motor grade in the right ankle was III. Her symptom duration was about 4 months. MRI showed severe soft disc herniation located in the central zone of L4–5 level. The patient underwent TELD with foraminoplasty under local anesthesia with intravenous

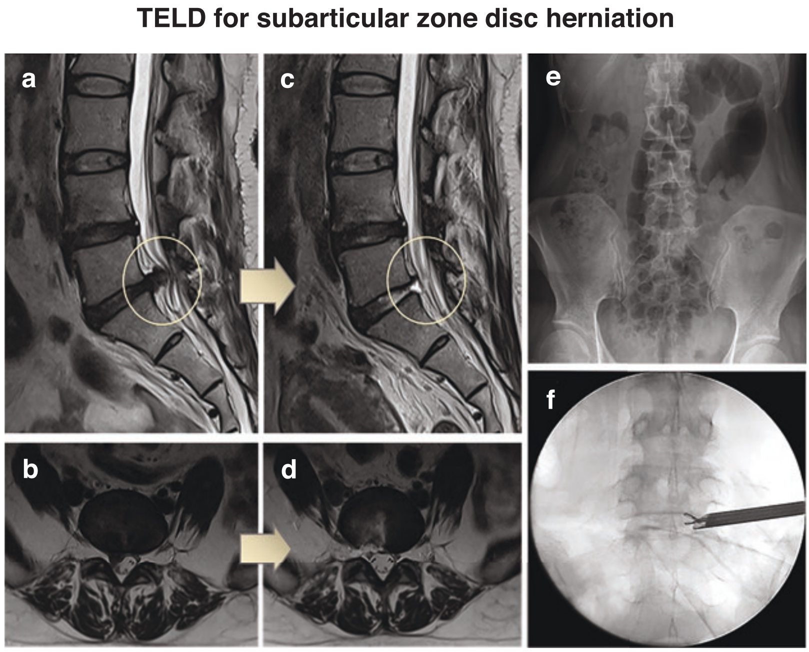


Fig. 31 TELD for subarticular zone disc herniation. A 31-year-old female patient presented with right leg radiating pain with decreased muscle strength. Preoperative MRI showed severe soft disc herniation located in the subarticular zone of L5-S1 level (**a**, **b**). She had a relatively wide width between both iliac crests (**e**). TELD was successfully performed with complete herniated disc removal and full decompression (**c**, **d**, **f**)

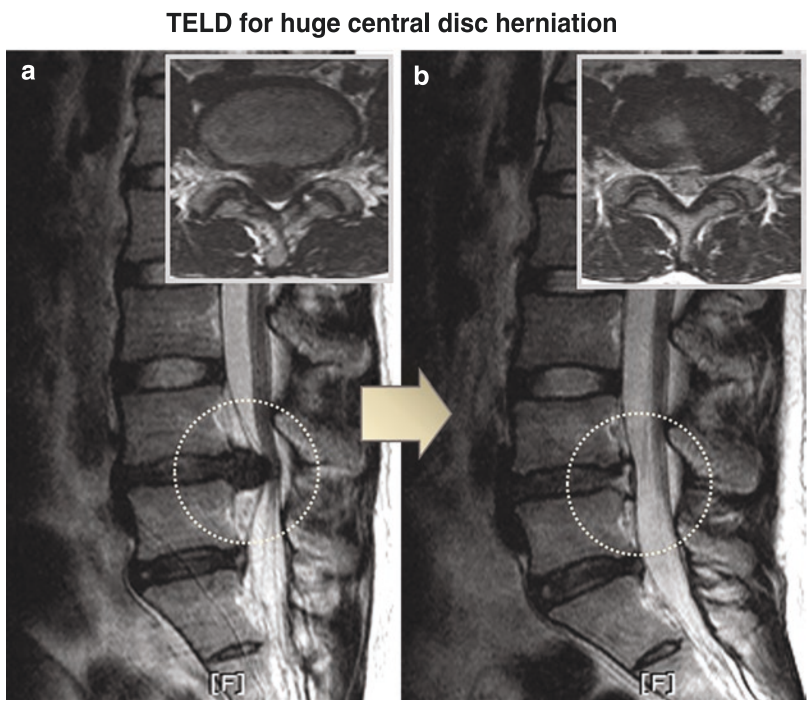


Fig. 32 TELD for huge central lumbar disc herniation. A 30-year-old female patient presented with right leg radiating pain. MRI showed huge central disc herniation at the L4–5 level (**a**). TELD was performed under local anesthesia. Successful removal of herniated disc was achieved (**b**), and her symptoms recovered immediately after the procedure

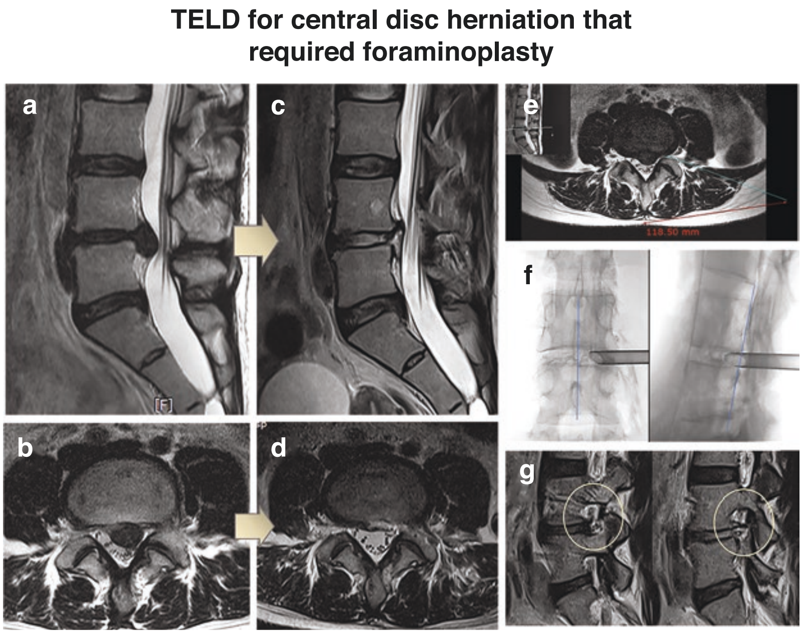


Fig. 33 TELD for central disc herniation that required foraminoplasty. Preoperative MRI of a 32-year-old female patient showed severe soft disc herniation located in the central zone of L4-5 level (**a**, **b**). TELD was performed after skin entry point determination (**e**), but access close to the medial pedicular line was not achieved during initial approach. As a result, the working cannula was not positioned in the ideal position (**f**). Foraminoplasty was required for successful TELD (**g**, **c**, **d**)

sedatives. At the initial approach, access was not close to the medial pedicular line. As a result, the working cannula was not positioned in the ideal position and moved away from the target. After retreating the working cannula again, foraminoplasty was carried out, and successful removal of the herniated disc was achieved by approaching the target closer. Immediately after the TELD, the VAS decreased to 2. The patient's muscle strength was gradually recovered (Fig. 33).

5.4 Case 4 (Contralateral Approach of TELD in Case of Conjoined Nerve Root)

A 54-year-old female patient visited our hospital with severe radiating pain in the left lower extremity that had persisted for two months. Her symptoms did not improve with conservative treatments including epidural block, physical therapy, and pain medications. The preoperative VAS score was 7 points. Preoperative radiographic findings revealed that the patient had extruded disc herniation from the central to the left subarticular zone and left conjoined nerve roots. TELD was performed with contralateral approach under local anesthesia with intravenous sedatives. Postoperative MRI showed complete removal of the herniated disc and successful decompression. After TELD, she improved to a VAS score of 1 and recovered without any sequelae (Fig. 34).

5.5 Case 5 (TELD for Sequestrated Disc Herniations Migrated Beyond the Disc Level)

A 51-year-old male patient presented with severe lower extremity radiating pain. The patient had a motor power of ankle dorsiflexion of grade III to IV and a positive straight leg raising (SLR) test at <45°. Preoperative MRI showed sequestrated disc herniation with caudal migration. The patient underwent TELD under local anesthesia with intravenous sedatives. TELD was successful and foraminoplasty was required to remove the herniated disc fragments. The patient's symptoms and signs completely recovered (Fig. 35).

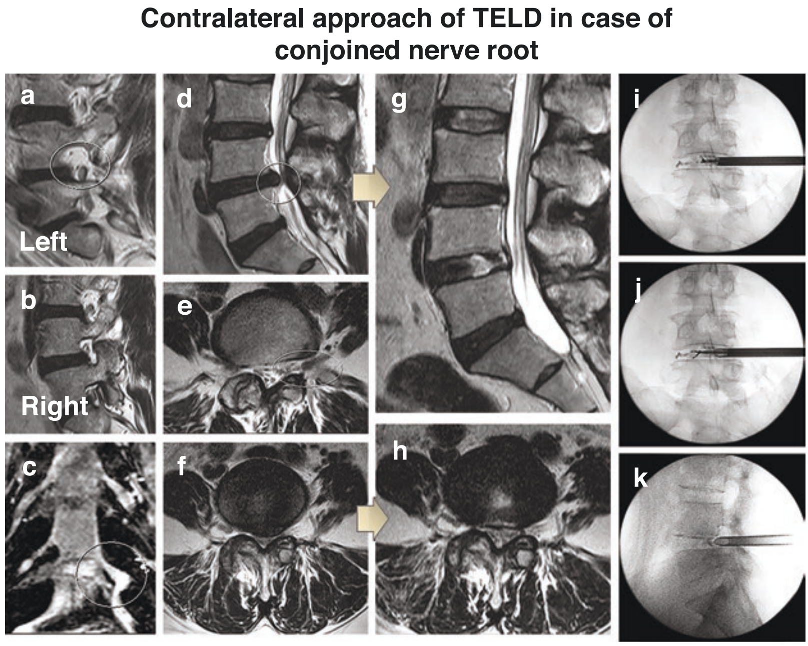


Fig. 34 Contralateral approach of TELD in case of conjoined nerve root. A preoperative MRI of a 54-year-old female patient with radiating pain in the left lower extremity showed left intracanal disc herniation (**d**, **f**) and left conjoined nerve root (**a**, **c**, **e**) at L4–5 level, and the right side showed normal nerve travel (**b**). Complete removal of the herniated disc and successful decompression (**g**, **h**) was achieved by performing TELD with a contralateral approach (**i**, **j**, **k**)

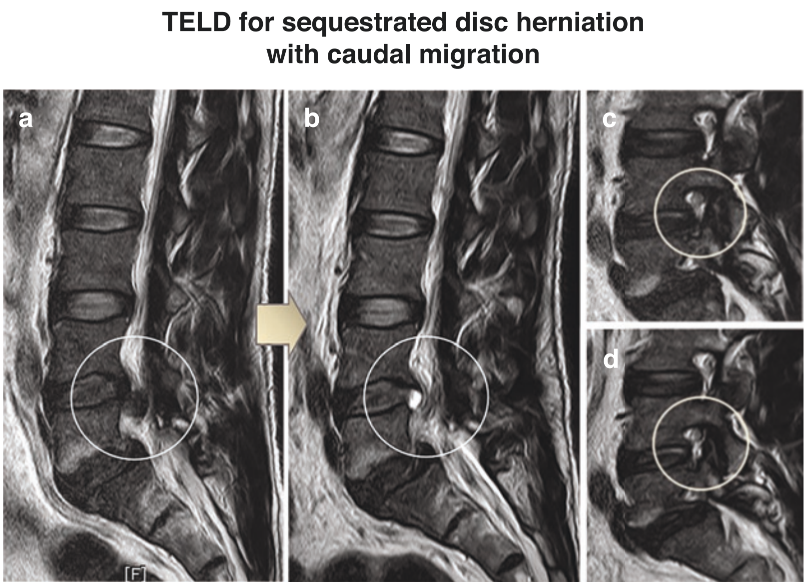


Fig. 35 TELD for sequestrated disc herniation with caudal migration. A 51-year-old male patient presented with severe lower extremity radiating pain. Preoperative MRI showed sequestrated down-migrated disc herniation (**a**) with not wide foraminal dimension (**c**). The patient underwent TELD under local anesthesia with intravenous sedatives. TELD was successful and foraminoplasty was required to remove the herniated disc fragments (**b**, **d**)

5.6 Case 6 (TELD Without Foraminoplasty for the Treatment of Down-Migrated Disc Herniation)

A 58-year-old male patient presented with lower back pain with radiating leg pain. The pain has been sustained for about 6 weeks without responding to conservative treatments. On MR imaging, down-migrated disc herniation was seen at the L3–4 level with a relatively wide intervertebral foramen. TELD was performed under awakened anesthesia. Successful TELD was performed without foraminoplasty. His symptoms disappeared and he was discharged the next day without any complications (Fig. 36).

5.7 Case 7 (Unsuccessful Outcome Case of TELD)

A 44-year-old male patient visited our hospital with severe radiating pain in the left lower extremity. Preoperative radiologic study showed down-migrated soft disc herniation. TELD was performed with foraminoplasty under local anesthesia with intravenous sedatives. Postoperative MRI showed herniated disc removal and decompression, and the patient was discharged with improvement of symptoms the next day. After 8 weeks, the patient was revisited with severe radiating pain in the lower extremities, and follow-up MRI showed recurrence at the same location. The patient underwent open microdiscectomy and recovered again. The patient had two poor prognostic factors: Modic change and endplate calcified osteosclerosis around the base of herniation (Fig. 37).

5.8 Case 8 (TELD for Highly Down-Migrated Disc Herniation with Grade 1 Spondylolisthesis)

A 31-year-old male patient visited our hospital with decreased muscle strength and severe radiating pain in the right lower extremity. The VAS score was 7, and the motor power of big toe dorsiflexion was grade I ~ II with straight leg raising (SLR) test positive at <30°. Preoperative radiologic study showed highly down-migrated disc herniation and grade I spondylolisthesis without significant instability. TELD was performed with foraminoplasty under local anesthesia with intravenous sedatives. Postoperative MRI showed complete herniated disc removal and full decompression. His symptoms and signs showed a rapid recovery after the procedure, and a dynamic x-ray after 6 years of the last follow-up showed a stable spine (Fig. 38).

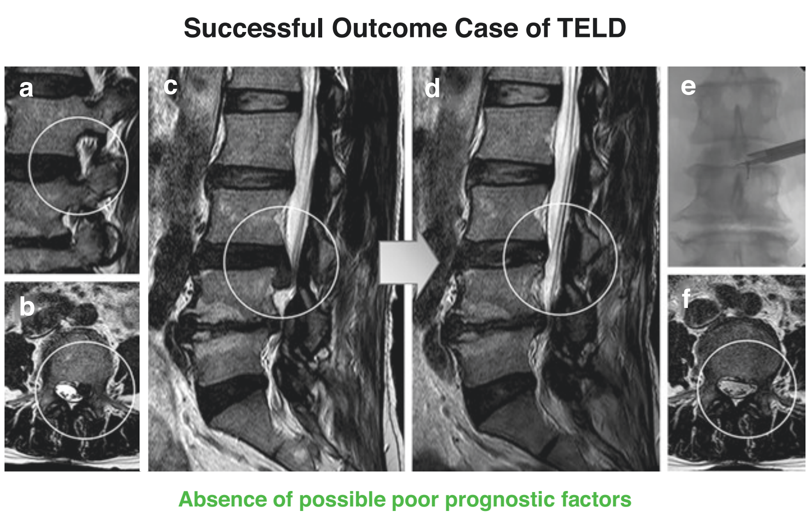
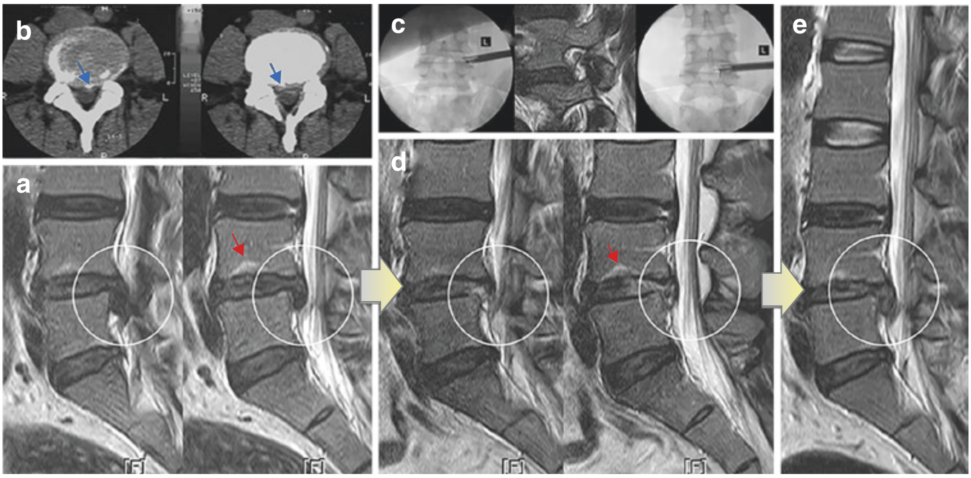


Fig. 36 TELD without foraminoplasty for the treatment of down-migrated disc herniation. In the preoperative radiological findings of a 58-year-old male patient with radiating leg pain, there were no unfavorable prognostic factors at the index level, and severe down-migrated disc herniation was observed with a relatively wide intervertebral foramen (**a**–**c**). Successful TELD was performed without foraminoplasty (**d**–**f**)

Unsuccessful Outcome Case

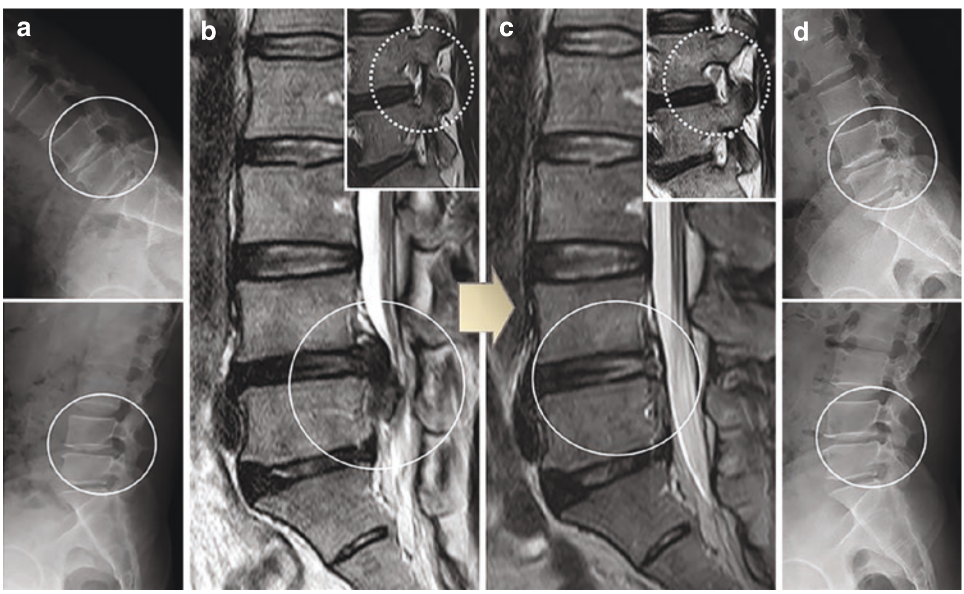


TELD with foraminoplasty **Recurrence after 8 weeks**

Poor prognostic factors: Modic change, osteosclerosis

Fig. 37 Unsuccessful Outcome Case of TELD. A preoperative MRI of a 44-year-old male patient with severe leg pain showed down-migrated soft disc herniation (**a**). MRI after TELD with foraminoplasty (**c**) showed herniated disc removal and decompression (**d**). After 8 weeks, follow-up MRI showed recurrent disc herniation (**e**). The patient underwent open microdiscectomy and recovered again. The patient had two poor prognostic factors: Modic change (**a**, red arrows) and endplate calcified osteosclerosis around the base of herniation (**b**)

TELD for highly down-migrated disc herniation with Gr I spondylolisthesis



Transforaminal Approach (With Foraminoplasty)

Follow-up: 76 month, VAS 7 => 0, ODI => 2%

Fig. 38 TELD for down-migrated disc herniation with grade 1 spondylolisthesis. A 31-year-old male patient presented with severe radiating leg pain with straight leg raising (SLR) test positive at <30°. Preoperative MRI (**b**) and X-ray (**a**) showed highly down-migrated disc herniation and grade I spondylolisthesis. Successful TELD was performed with foraminoplasty (**c**), and a dynamic X-ray after 6 years of the last follow-up showed a stable spine (**d**). Patients with Positive SLRT

5.9 Case 9 (TELD for Up-Migrated Disc Herniation)

A 78-year-old male patient presented with right leg radiating pain. The visual analogue scale (VAS) score was 8, and the motor grade of the left knee extension power was II–III. MRI showed up-migrated disc herniation at the L3–4 level. The patient underwent TELD with foraminoplasty under local anesthesia with intravenous sedatives. Full decompression was achieved after TELD. The patient had complete resolution of his symptoms (Fig. 39).

5.10 Case 10 (TELD for Highly Up-Migrated Disc Herniation)

A 30-year-old female patient presented with severe radiating leg pain. On MR imaging, a highly up-migrated disc herniation was seen at the L4–5 level. Successful TELD was performed with foraminoplasty, and the patient was discharged with improvement of symptoms the next day (Fig. 40).

5.11 Case 11 (TELD for Upper Lumbar Disc Herniation)

A 35-year-old male patient visited our hospital suffering from radiating pain in both lower extremities and muscle weakness. He also had symptoms of voiding difficulty. Preoperative MRI showed soft disc herniation with severe nerve compression at L1–2 level. TELD was performed for ventral decompression without further deterioration due to nerve retraction or irritation. It was conducted outside-in tactic and TELD was very successful. The patient showed a rapid recovery and was fully recovered (Fig. 41).

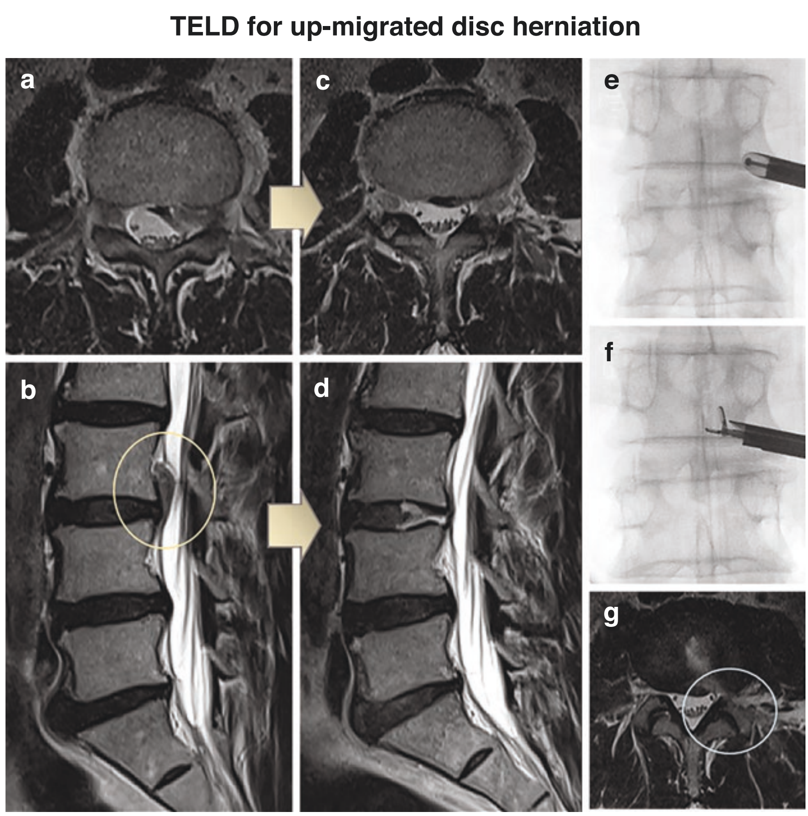


Fig. 39 TELD for up-migrated disc herniation. A 78-year-old male patient presented with right leg radiating pain. MRI showed up-migrated disc herniation at the L3-4 level (**a**, **b**). The patient underwent TELD with foraminoplasty (**e**, **f**, **g**). Full decompression was achieved after TELD (**c**, **d**)

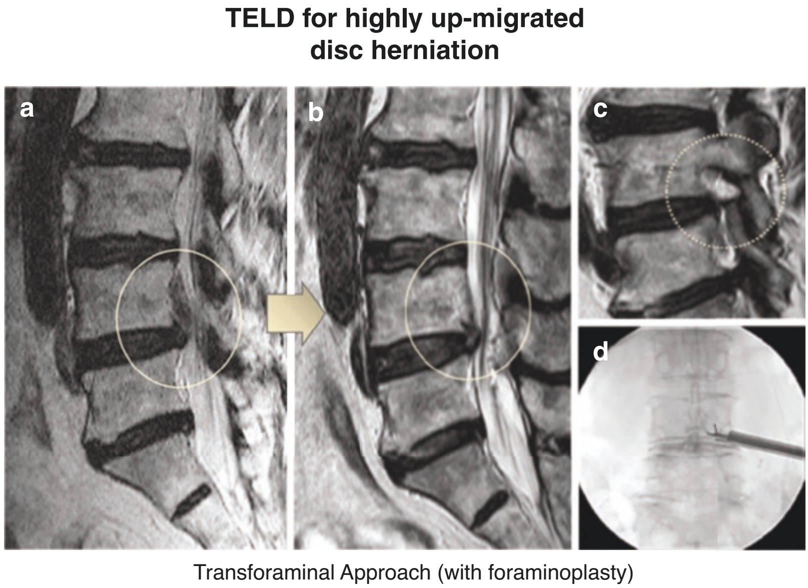


Fig. 40 TELD for highly up-migrated disc herniation. Preoperative MRI of a 30-year-old male patient with severe leg pain showed highly up-migrated disc herniation at L4-5 level (**a**). The TELD procedure achieved complete removal of the herniated disc fragments (**b**) and required a foraminoplasty to access the target area (**c**, **d**)

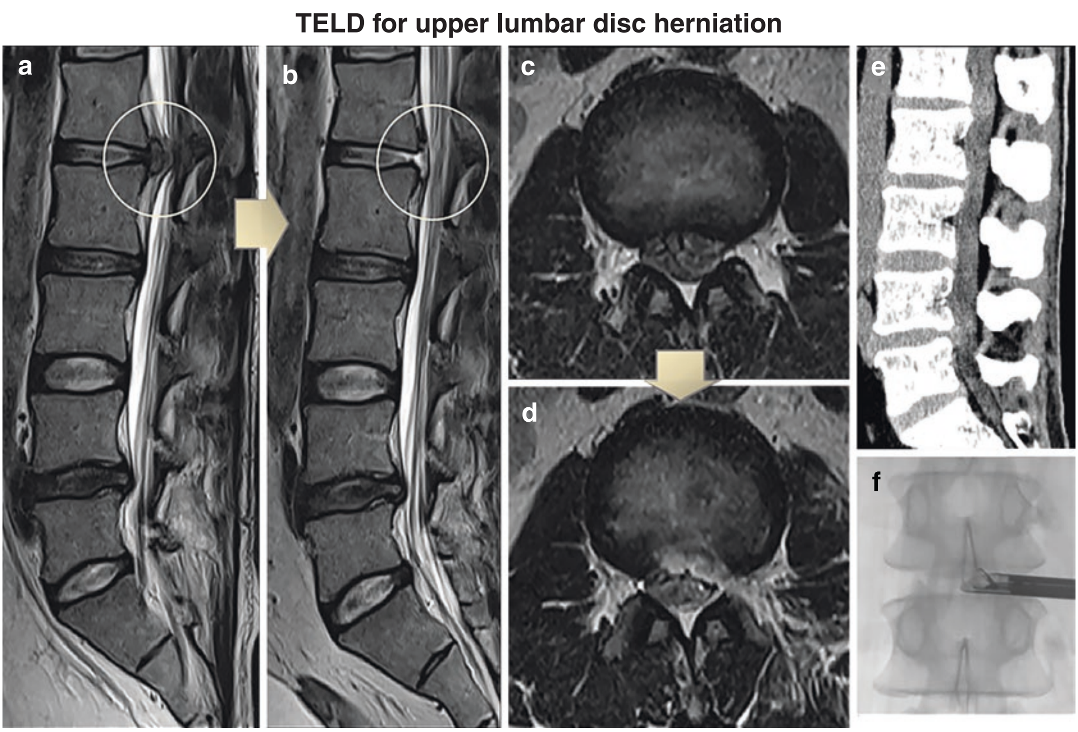


Fig. 41 TELD for upper lumbar disc herniation. Preoperative MRI of a 35-year-old male patient with imminent cauda equina syndrome showed extreme nerve compression by a severe soft herniated disc at the L1-2 level (**a**, **c**, **e**). The TELD procedure allowed complete removal of herniated disc and rapid recovery through ventral decompression without nerve retraction (**b**, **d**, **f**), which is the most powerful advantage of TELD

6 Summary

The effective use of advanced approach techniques and the appropriate selection of patients with good indications are essential for the successful outcome of transforaminal endoscopic lumbar discectomy. First of all, it is important to know the accessible range of the endoscopic forceps. The reason is that for appropriate patient selection, clinical and radiological findings as well as technical feasibility should be included in the considerations for indications. The advanced techniques required for successful herniated disc removal are also methods of approaching the herniated disc fragments so that they are located within the reachable range of the endoscopic forceps.

Specifically, the finite length of the actuating jaw of the endoscopic forceps from the point at which the endoscopic working cannula reaches the target as close as possible will be the accessible range of the endoscopic forceps. The reach of this limited length of endoscopic forceps may vary in reachable distance due to the characteristics of TELD requiring an approach angle. In order to utilize this reach to the maximum length, an accurate targeting process with an appropriate entry angle is required. Also, the correct selection of the primary target point, skin entry point, and annulus entry point is important for this. Positioning the working cannula of the endoscope as close to the target as possible requires effective use of obturator insertion technique and utilization of foraminoplasty as well as proper access trajectory.

Appropriate annular releasing and levering and rotational movement of the endoscopes also help to get closer to the target. In order to effectively remove the herniated disc and prevent remaining fragments, sufficient work around the target disc fragments should be performed to ensure a clear view and free space for the herniated disc to be retrieved. Selection of an appropriate endoscopic forceps and its proper use are also necessary to prevent residual disc.

The success or failure of TELD for the treatment of lumbar disc herniation is highly dependent on whether the endoscopic forceps can reach a position where it can capture herniated disc fragments. The most important principle of approach technique in TELD is to approach the target safely and as close to the target as possible. Appropriate patient selection by identification of prognostic factors and utilization of advanced techniques will enable TELD to provide the means for a consistent successful resolution.

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