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The unilateral biportal endoscopy journey: proposing a 10-tier difficulty progression framework for unilateral biportal endoscopy

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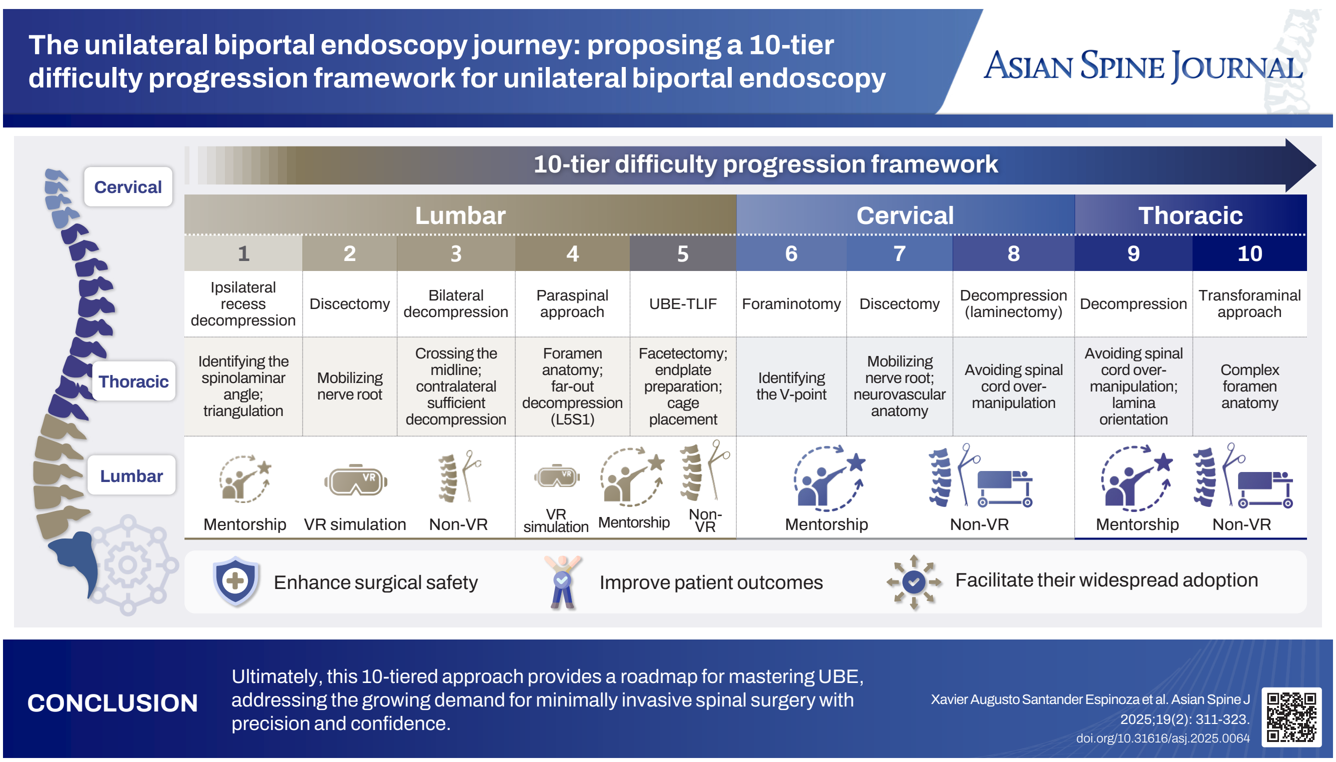

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The unilateral biportal endoscopy journey: proposing a 10-tier difficulty progression framework for unilateral biportal endoscopy

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Unilateral biportal endoscopy (UBE) has revolutionized minimally invasive spinal surgery, offering enhanced visualization and reduced recovery times. However, the steep learning curve and technical complexity require a structured training framework. This narrative review proposes a 10-tier difficulty progression framework for UBE designed to guide novice surgeons through incremental skill acquisition. Each tier corresponds to specific procedures with escalating challenges spanning lumbar, cervical, and thoracic pathologies. The proposed framework begins with foundational lumbar procedures, such as ipsilateral recess decompression and discectomy, and advances to more intricate techniques, such as transforaminal lumbar interbody fusion. Transitioning to the cervical and thoracic regions requires mastery of earlier tiers, emphasizing precision in handling delicate anatomical structures. These challenges include achieving proficiency in mobilizing nerve roots, minimizing spinal cord manipulation, and mastering advanced decompression techniques. Evidence from learning curve analyses, including cumulative sum methodologies, underscores the importance of tailored training to reduce complications and optimize outcomes. By standardizing the progression of UBE procedures, this framework aims to enhance surgical safety, improve patient outcomes, and facilitate their widespread adoption. Future research should focus on validating this framework by using clinical trials, training feedback, and long-term patient data. Ultimately, this 10-tiered approach provides a roadmap for mastering UBE, addressing the growing demand for minimally invasive spinal surgery with precision and confidence.

Keywords: Endoscopy; Biportal; Progression; Learning curve; Education

Introduction

Unilateral biportal endoscopy (UBE) or biportal endoscopic spine surgery (BESS) is increasingly adopted in spine surgery because of its minimal invasiveness and faster recovery, although it demands rigorous training and stepwise skill development [1-3]. Unlike open or tubular methods, UBE/BESS requires advanced hand-eye coordination and proficiency with a dual-portal system. Progression from basic lumbar to advanced thoracic and cervical procedures requires a structured learning pathway. This paper proposes a 10-level framework correlating surgical complexity, required dexterity, and anatomical challenges, where each level builds on previously mastered skills and knowledge.

General Current Indications

The indications for UBE cover several applications, with lumbar, cervical, and thoracic approaches being suitable for nearly all the same conditions treated with microscopic or tubular techniques [4]. Over time, the scope of UBE has expanded to include less common conditions, such as tumors and tuberculosis debridement with stabilization via transforaminal lumbar interbody fusion (TLIF) [5,6]. However, this broader application often leads to variability in outcomes because many reports are based on individual cases.

The most frequent uses of UBE in the literature are presented in Table 1. Although this table is not comprehensive, it compels the most common pathology reported in the literature.

Learning Curve and Number of Cases

Determining the number of cases required to achieve mastery may appear straightforward, but various factors influence the point at which true expertise is attained. This is particularly relevant because some UBE practitioners already possess extensive full-endoscopic experience, substantially reducing the learning curve. However, the learning curve of a naïve surgeon can vary among individuals depending on many factors. To date, only a few studies have evaluated the learning curve of UBE; some have focused on specific pathologies, whereas others have addressed it more generally [7-15] (Table 2).

The cumulative sum (CUSUM) method is particularly

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well-suited for learning curve analysis in surgical procedures due to its ability to provide a detailed and dynamic assessment of performance over time. Unlike traditional methods, CUSUM is highly sensitive to incremental changes, offering precise identification of the transition from the learning phase to the mastery phase. Unfortunately, few studies have considered this method to express the learning curve analysis of UBE [7-10].

Generally, the learning curve for uniportal and biportal endoscopy differs depending on the technique and pathology addressed. Achieving proficiency in uniportal endoscopy takes approximately 30.1 cases, whereas biportal approaches typically require around 38.7 cases, likely due to the added complexity of coordinating two working channels. For specific procedures like lumbar interbody fusion, uniportal methods reach mastery in approximately 27.5 cases, while biportal can take up to 41 [16,17].

Table 1. Most common indications for unilateral biportal endoscopy

Region	Pathology	Specific pathology
Lumbar	Disc herniation	Central, paracentral, recessal
		Foraminal, extraforaminal
		Re-herniation (redo-surgery)
		Migrated
		Sequestered
	Stenosis	Recessal
		Central
		Foraminal
		Facet cyst
	Spondylolisthesis	Grade I
		Grade II
Cervical	Disc herniation	Paracentral
		Foraminal
	Stenosis	Spondylotic
		With or without myelopathy
Thoracic	Disc herniation	Paracentral
		Foraminal
		Non calcified
	Stenosis	Ossification of ligamentum flavum
		Central
		Recessal
		Foraminal

Ten-Tiered Framework

This proposal is intended to help novice surgeons chart their journey through the learning curve of biportal endoscopy. While many methods can be utilized, we believe that guidelines and standardization can be extremely helpful at the beginning (Fig. 1).

This proposed progression framework categorizes biportal endoscopy procedures into 10 tiers/generations, each representing a technique with increasing levels of complexity. These generations are distributed under the umbrella of lumbar, cervical, and thoracic pathology (Fig. 2).

Each tier has some specific pathology with recommendations to start with accordingly, based on a certain level of experience, to be executed safely (Table 3). The rationale used to separate each generation has to

Table 2. Studies with learning curve analysis of UBE on different spinal regions

Author	Surgeons	Learning curve type of analysis	Region and pathology	Total no. of series	Required no. of cases
Choi et al. [14]	1	Observational analysis focused on operation times and complication rates.	Lumbar disc herniation; lumbar stenosis; synovial cysts	68	14 (disc herniation); 36 (various pathologies)
Easthardt et al. [10]	1	CUSUM	Lumbar disc herniation; lumbar stenosis	63	31
Guo et al. [9]	1	CUSUM; RA-CUSUM	Lumbar stenosis (fusion required)	184	29 (stabilization); 41 (risk adjusted)
Kim et al. [13]	1	Nonparametric regression using locally weighted scatterplot smoothing	Lumbar stenosis with spondylolisthesis Istmic spondylolisthesis	57	34
Xu et al. [8]	1	CUSUM; RA-CUSUM	Lumbar disc herniation; lumbar stenosis	197	54 (stabilization); 89 (risk adjusted)
Chen et al. [11]	5	CUSUM	Lumbar disc herniation	144	41–45 (with prior experience)
Li et al. [12]	1	CUSUM	Lumbar disc herniation	120: 87 (uni), 33 (UBE)	40 (full); 15 (UBE)
Kang et al. [7]	1	LC-CUSUM	Foraminal cervical stenosis	50	20
Park et al. [15]	1	LC-CUSUM	Lumbar stenosis	60	58 (no prior experience)

UBE, unilateral biportal endoscopy; CUSUM, cumulative summation; RA-CUSUM, risk analysis cumulative summation; LC-CUSUM, learning curve cumulative summation.

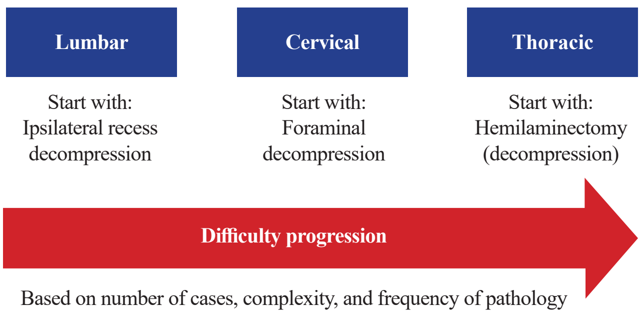

Fig. 1. General difficulty progression in unilateral biportal endoscopy by region.

Region	Tier	Procedure
Lumbar region 5 tiers/generations	1	Lumbar lateral recess decompression
	2	Lumbar discectomy
	3	Lumbar bilateral decompression
	4	Lumbar extraforaminal approach
	5	Lumbar UBE-TLIF
Cervical region 3 tiers/generations	6	Cervical foraminotomy
	7	Cervical discectomy
	8	Cervical bilateral decompression
Thoracic region 2 tiers/generations	9	Thoracic uni/bilateral decompression
	10	Thoracic transforaminal approach

Fig. 2. The 10-tier framework difficulty progression for biportal endoscopy. UBE, unilateral biportal endoscopy; NR, nerve root; TLIF, transforaminal lumbar interbody fusion.

Table 3. Main challenges of the 10 tiers of unilateral biportal endoscopy or biportal endoscopic spine surgery

Generation	Procedure	Main challenge
Lumbar		
Tier 1	Ipsilateral recess decompression	Identifying the spinolaminar angle; triangulation
Tier 2	Discectomy	Mobilizing nerve root
Tier 3	Bilateral decompression	Crossing the midline; contralateral sufficient decompression
Tier 4	Paraspinal approach	Foramen anatomy; far out decompression (L5S1)
Tier 5	Transforaminal lumbar interbody fusion	Facetectomy; endplate preparation; cage placement
Cervical		
Tier 6	Foraminotomy	Identifying the V-point
Tier 7	Discectomy	Mobilizing nerve root; neurovascular anatomy
Tier 8	Decompression	Avoiding spinal cord over-manipulation
Thoracic		
Tier 9	Decompression	Avoiding spinal cord over-manipulation; lamina orientation
Tier 10	Foraminotomy	Complex foramen anatomy

do with complexity (i.e., number of steps and maneuvers to execute), frequency of the pathology, associated risks, and reported outcomes.

First tier/generation: lumbar lateral recess decompression

This procedure is the foundation of the UBE/BESS training. It involves decompressing the lateral recess in the lumbar spine, allowing surgeons to familiarize themselves with the biportal system, endoscopic visualization, and basic decompression techniques. This involves identifying the spinolaminar angle as the starting point of the procedure. From here on, the surgeon will be able to progress to more complex surgeries.

Second tier/generation: lumbar discectomy

In this tier, surgeons progress to address the disc, decompressing not only the lateral recess but also removing lateral, central, migrated, and revision surgery (i.e., re-herniation). These scenarios require greater precision and adaptability to variations in disc pathology. In this scenario, nerve root manipulation is almost always required, and ensuring that it is performed safely is the primary challenge. Moreover, because UBE can be tailored to each case, it allows us to minimize bone removal based on the specific type of herniation, which in turn calls for significant experience. Once these challenges have been overcome and the surgeon is comfortable performing left-sided approaches, they can incorporate right-sided approaches for right-sided pathologies. The primary difficulty for right-handed surgeons is the unnatural angle of the approach.

Third tier/generation: lumbar bilateral decompression

This approach marks a step forward from ipsilateral recess decompression by enabling access to the contralateral medial side of the superior articular process from one side. Removing this structure ensures thorough decompression of the nerve root. In addition, the ability to palpate both the ipsilateral and contralateral pedicles, which is crucial for this type of decompression, demands finesse. At this stage, the contralateral approach is used to remove facet cysts or access the sublaminar region for specific foraminal herniations. The primary challenge lies in managing the midline dural fold created by hydrostatic pressure, which is a frequent site of dural tears in less experienced surgeons.

Fourth tier/generation: lumbar extraforaminal approach

The extraforaminal approach is fundamentally different. It demands a thorough understanding of the paraspinal vascular anatomy and foraminal anatomy. In fact, both the incisions and bony landmarks vary significantly from standard techniques. Initially, levels L1–L4 are preferable because the foraminal area is easier to identify. From there, L5–S1 introduces the concept of far-out decompressions, which test spatial awareness and the ability to access more challenging regions. Proper manipulation, mobilization, and release of the nerve root in its extraforaminal path are essential, as are skills in foraminoplasty and extraforaminal disc herniation removal. Additionally, switching to a 30° or 45° endoscopic view allows experienced surgeons to extend their reach from the extraforaminal region to the recess and achieve further decompression.

Fifth tier/generation: lumbar UBE-TLIF

TLIF using UBE has a considerably higher level of complexity. It demands proficiency in interlaminar and genuine transforaminal approaches, as well as precise implant placement and disc space preparation. In addition, incisions must be adapted for each patient, requiring flexibility and adaptability from the surgeon. Ideally, the same incisions should be used for screw placement, necessitating a solid understanding of triangulation and versatility. As with open TLIF, the key predictors of successful fusion are proper endplate preparation and correct implant selection and positioning. At this stage, surgeons must be capable of performing extensive decompressions, complete facetectomies, and, if necessary, spondylolisthesis reduction, all through extremely narrow corridors.

Transitioning to the cervical region requires several surgeries in the lumbar region, which comprises most of the pathology of the spine. While there are no exact recommendations regarding when to progress or how many lumbar cases are needed, it is safe to say that expertise and very good handling of instruments are demanded [7,18,19].

Sixth tier/generation: cervical foraminotomy

Transitioning to the cervical spine, foraminotomies demand greater precision owing to the smaller working space and proximity to critical neurovascular structures. Here, the challenge is the presence of the spinal cord, which requires minimal manipulation. The surgeon must be able to identify the “V” point, which is the junction of the superior and inferior lamina, where they transition to become the facet joints. Additionally, patient selection and positioning at the operating table are very important factors to keep in mind if we are looking for a smooth surgical experience.

Seventh tier/generation: cervical discectomy

The next phase of the procedure focuses on removing ruptured disc fragments. This involves careful manipulation of the lateral border of the nerve root and addressing vascular adhesions on the medial side of the pedicle. Because this area is highly sensitive, it requires advanced surgical dexterity and flexibility. Surgeons must be able to perform effective foraminotomies to sufficiently expose the axillary segment of the nerve root and disc space. This approach ensures the complete removal of the ruptured fragments from the axillary region around the nerve root, considering the nerve root’s higher anatomical origin compared to the disc level, especially in lower segments such as C6–C7 and C7–T1.

Eighth tier/generation: cervical laminectomy

Building on cervical procedures, this phase extends to contralateral decompression via laminectomy. Surgeons must confidently cross the midline to ensure that the contralateral nerve root is clearly visible and decompressed, taking care to avoid undue manipulation of the spinal cord. Moreover, the use of thinner instruments (i.e., a 1 mm Kerrison) necessitates significant expertise and comfort with the technique. Advanced skills, such as preserving the ligamentum flavum during drilling, palpating both pedicles and removing the ligamentum flavum in one piece, are vital for achieving favorable surgical outcomes.

When approaching the thoracic region, it is important to recognize that thoracic pathologies are comparatively rare, and they often present with already established neurological symptoms. As a result, fewer cases and the associated learning curve can make attaining proficiency more time-consuming.

Ninth tier/generation: thoracic laminectomy

Thoracic spine surgery introduces unique challenges owing to anatomical constraints. Performing a laminectomy here requires a precise technique and a solid understanding of thoracic biomechanics. The most common cause of compression in this region is ossification of the ligamentum flavum (OLF), but not all OLF types are suitable for thoracic UBE; significant calcifications or tuberous forms are typically avoided. Paracentral disc herniation compromising the spinal cord is another indication for laminectomy in this area.

Tenth tier/generation: thoracic transforaminal approach

The thoracic transforaminal approach is considered the most intricate UBE technique and brings together all previous skills to address the thoracic spine's complex anatomy and pathologies. This far-lateral route is used to remove foraminal herniations or, in more advanced scenarios, place cages, such as procedures that involve laminectomy, facetectomy, and partial pediculectomy.

Discussion

General rationale

This structured progression offers a systematic approach to mastering BESS. By advancing through the tiers, surgeons develop their skills incrementally, reducing the risk of complications associated with premature attempts at complex procedures. However, learning curves vary owing to differences in prior endoscopic experience, surgical expertise, and case exposure. This framework allows for competency-based progression, enabling individualized training rather than adherence to a fixed case count.

Traditional mentorship-based training, although invaluable, often lacks standardization and depends on the availability of mentors. Virtual reality (VR) and simulation-based training enhance spatial awareness and motor skills but cannot fully replicate real tissue handling and intraoperative decision-making (Table 4). A hybrid training model integrating VR, non-VR simulation, cadaveric dissection, and mentorship bridges the gap between theoretical learning and real-case application. Studies have demonstrated that VR-assisted training improves precision and reduces complications, whereas cadaveric training provides hands-on experience that is crucial for anatomical navigation and surgical execution [20,21].

An integrated approach that combines the 10-tier framework, mentorship, VR, and non-VR simulation models offers a structured and adaptive learning pathway. Future research should focus on refining this approach to enhance accessibility and standardization, particularly for trainees and novice surgeons.

Integration of training methods into the framework

To optimize UBE training, a tiered implementation strategy leverages different educational tools at each

Table 4. Comparison of features between the framework vs. mentorship vs. simulation

Feature	10-Tier framework	Mentorship-based training	VR simulation
Structure & standardization	Clearly defined, step-by-step progression with objective skill milestones.	Highly variable depending on mentor expertise, experience, and availability.	Structured but varies by platform and simulation quality.
Learning curve assessment	Based on CUSUM and objective performance metrics to track skill acquisition.	Mostly subjective, based on mentor's evaluation of the trainee's readiness.	Can provide objective feedback on precision and motor skills but lacks real-time case complexity assessment.
Skill adaptability & personalization	Can be adapted based on surgeon's experience, allowing faster progression for skilled individuals.	Flexible to the trainee's needs but depends on mentor's teaching style.	Allows repetition of specific tasks but does not adjust dynamically to real-case variability.
Error tolerance & risk mitigation	Stepwise progression reduces errors by ensuring foundational skills before complex procedures.	Mentor intervention can prevent critical errors, but learning is case-dependent.	No patient risk; allows for unlimited practice of specific scenarios without consequences.
Availability & accessibility	Can be implemented in structured training programs worldwide.	Limited by availability of expert mentors.	Requires access to VR technology, which may not be widely available.
Cost & resource requirements	Moderate: relies on real surgical cases, but standardization reduces inefficiencies.	High: requires dedicated mentor time and clinical exposure.	High: VR setups, software, and simulation labs are expensive.
Effectiveness in UBE training	Provides a clear roadmap for surgical mastery with real-case experience.	Highly effective when mentors are experienced but inconsistent across training programs.	Enhances technical skill proficiency but lacks full real-case surgical complexity.
Integration with other methods	Can incorporate mentorship and VR-based simulation to optimize training.	Often used in combination with case observations and hands-on workshops.	Best when combined with real-case exposure to reinforce skills learned in a simulated setting.

VR, virtual reality; CUSUM, cumulative summation; UBE, unilateral biportal endoscopy.

stage. While the methods can always be used together in all stages, we believe they have some weight regarding the specific tier we are on (Fig. 3).

Tiers 1–3 (basic lumbar): VR and non-VR haptic models facilitate fundamental skills such as instrument handling, spatial orientation, and triangulation before transitioning to real cases under mentor supervision.

Tiers 4–5 (intermediate-advanced lumbar): A combination of simulation, mentorship, and real-case exposure refines technical execution. Procedures such as UBE-TLIF, which require precise haptic feedback for cage placement and endplate preparation, benefit from non-VR models and cadaveric training.

Tiers 6–8 (advanced cervical): Experience with lumbar procedures is essential before transitioning to cervical surgery. Cadaveric labs provide a safe environment to practice cervical foraminotomy before performing it on live patients, thus enhancing the precision when using nerve decompression and drilling techniques. To our knowledge, no VR simulators are currently available for the cervical region, specifically in UBE.

Tiers 9–10 (advanced thoracic): Given the complexity and risks associated with thoracic UBE, mentorship and adherence to the framework remain critical. At this level, the focus is on experienced users refining their skills and expanding indications, particularly for transforaminal approaches. A blend of mentorship and simulation can be used. Again, to the best of our knowledge, there are no specific simulations for this region.

VR-based training has demonstrated benefits in enhancing cognitive and motor learning in spinal surgery [21-23]. However, its structured integration into UBE training remains underdeveloped. As a tool for early-stage training, VR facilitates hand-eye coordination and endoscopic visualization without patient risk.

Within our framework, VR is most applicable in the lumbar region, where software development and metric-based evaluations are more advanced. Case-specific VR modules can support preoperative planning and execution of more complex procedures, such as extraforaminal decompression, if available. In such cases, VR provides simulation-based rehearsal, allowing trainees to refine their approach before performing real cases [20].

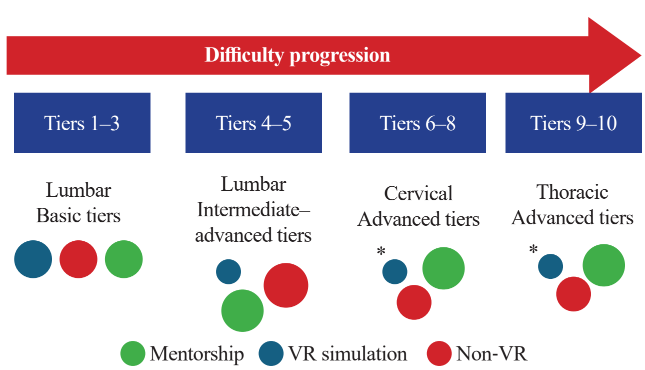

Fig. 3. Implementation of educational methods into the unilateral biportal endoscopy framework. VR, virtual reality. In each tier, the size of the circle represents the weight/importance of the particular educational method. Symbol (*) indicates "when available."

At more advanced stages, a combination of mentorship and non-VR simulations (haptic models and cadaver training) enhances training by providing tactile feedback for critical techniques. Non-VR haptic models, such as Endoscopic LumbarBox (UpSurgeOn SRL, Lombardo, Italy) and RealSpine Basic Endo (Realist, Leipzig, Germany), complement VR by offering realistic soft tissue dissection, nerve mobilization, and drilling simulations. These models help refine dexterity and instrument control, bridging the gap between theoretical learning and real-case exposure [21].

Although haptic models improve spatial awareness and technical precision, they do not fully replicate intraoperative variability and dynamic tissue interactions. Further research is needed to evaluate their effectiveness compared with VR and real-case training, particularly in UBE applications.

Competency-based progression and milestones in UBE training

Unlike a fixed case number approach, competency-based training ensures progression based on skill mastery. The CUSUM methodology, which is widely used in surgical education, highlights non-linear learning curves [8]; for instance, UBE-TLIF proficiency is generally achieved after 29–41 cases, with a corresponding drop in complication rates [9]. Furthermore, many surgeons practicing UBE nowadays come from the full-endoscopy world [11], which makes us reflect on the need to provide certain milestones/objectives to make the framework flexible.

By implementing structured competency milestones (Table 5), the framework adapts to individual learning speeds, thereby ensuring a personalized and effective training experience. As a complement, procedure-specific evaluation checklists validated by expert consensus can be used to track these personalized advances.

To further validate the framework's effectiveness, future research should validate the effectiveness of this structured framework with clinical trials assessing long-term patient outcomes across different tiers, multi-center studies to ensure framework applicability in diverse surgical settings and standardization of competency

Table 5. Competency-based milestones for each tier in UBE training

Region	Procedure	Proposed milestone
Lumbar		
Tier 1	Lateral recess decompression	• Triangulation over the spinolaminar angle • Identification of the lateral border of the NR • Bleeding control
Tier 2	Disc herniation	• Safe NR mobilization • Controlled disc fragment removal
Tier 3	Bilateral decompression	• Contralateral pedicle palpation • Midline dural fold management
Tier 4	Extraforaminal approach	• Paraspinal dissection mastery • Navigation around the foramen
Tier 5	UBE TLIF	• Thorough endplate preparation • Cage placement
Cervical		
Tier 6	Foraminotomy	• Identification of the V-point • Perineural membrane handling • Controlled foraminotomy
Tier 7	Discectomy	• Safe axillary NR decompression • Disc fragment clearance • No excessive cord manipulation
Tier 8	Laminectomy	• Midline crossing for contralateral decompression • Ligamentum flavum *en-bloc* resection
Thoracic		
Tier 9	Laminectomy	• Controlled OLF resection • Minimal spinal cord manipulation
Tier 10	Transforaminal approach	• Deep anatomical knowledge • Safe foraminal decompression (avoid excessive bone removal) • Avoid manipulation of the spinal cord

UBE, unilateral biportal endoscopy; NR, nerve root; TLIF, transforaminal lumbar interbody fusion; OLF, ossification of the ligamentum flavum.

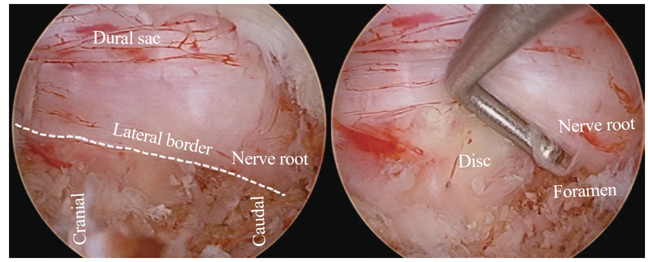

Fig. 4. The ipsilateral decompression by biportal endoscopy is the work horse and basic procedure to master in the lumbar region.

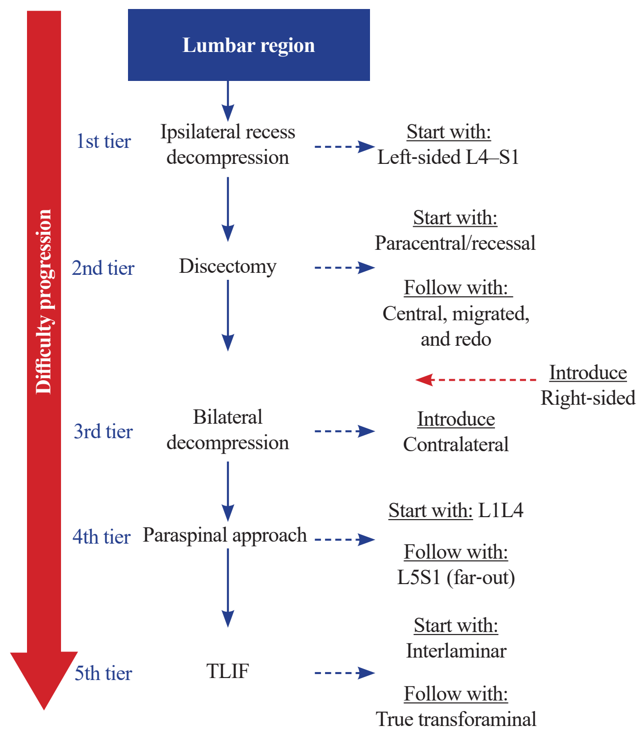

Fig. 5. Lumbar tiers for unilateral biportal endoscopy difficulty progression. TLIF, transforaminal lumbar interbody fusion.

evaluation tools, integrating CUSUM analysis, checklists, and VR-based performance tracking [8,9,20,21].

Specific rationale

Lumbar region and its generations

UBE is widely indicated for lumbar conditions, such as herniated discs, spinal stenosis, and spondylolisthesis [24]. Since it comprises the vast majority of degenerative spinal diseases, it is only logical that this should be the starting point of any UBE journey.

Ipsilateral recess decompression can achieve good results when complete decompression (i.e., seeing the lateral border of the nerve root) is achieved [25] (Fig. 4). Decompression and discectomy using this technique effectively address nerve root compression and stenosis, with a reported improvement in patient outcomes once proficiency is achieved [10]. Paraspinal approaches are particularly useful in cases of foraminal-extraforaminal pathology and for performing true transforaminal fusions. Redo-surgeries with UBE can help dissect and visualize scar tissue or even avoid it completely [8]. For more complex pathologies, such as migrated disc herniations or degenerative instability that requires fusion, UBE can offer a minimally invasive approach with improved visualization and reduced muscle trauma [9] (Fig. 5).

Mastering the indications in this region requires significant investment in training and experience. For lumbar decompression procedures such as laminectomy and diskectomy, the learning curve stabilizes after approximately 31 cases, with operative time reducing from 87 to 52 minutes and a notable decrease in complication rates [10]. For simple disc herniations (i.e., paracentral, not migrated), the cutoff can be somewhere around 15–20 cases [12]. Similarly, UBE-TLIF shows a proficiency cutoff between 29 and 41 cases, with the operative time dropping significantly in the mastery phase [9,13]. General analyses across multiple studies indicate that for various UBE procedures, the average learning curve stabilizes after 32 cases [17]. The learning curve can be greatly improved using structured programs focusing on endoscopic instrument handling and procedural sequences [24,26].

Complications during the early stages of the learning curve are relatively common, with issues such as dural tears, incomplete decompression, and nerve injuries frequently reported. For example, the complication rates drop significantly from 17.07% in the early phase to 2.6% in the mastery phase for UBE-TLIF, with fusion rates in this phase reaching up to 92.9%, and significant improvements in disability scores are noted at follow-up [9]. However, the complexity of cage placement and endplate preparation makes it essential to attempt this procedure after mastering simpler decompression and discectomy techniques. Proficiency in this technique reduces the operative time by nearly 40% and minimizes complications from 16.4% to 3.2%, underscoring the importance of experience [16].

The above literature suggests that mastering UBE procedures demands progressively more complex skills, making a staged approach to training essential. This also involves increasing the steps to achieve specific surgical goals, such as decompression, discectomy, or fusion. The foundational technique is ipsilateral recess decompression, which begins with identifying the spinolaminar angle and medial aspect of the facet joint complex. This phase focuses on the bony work to decompress the nerve root without disturbing the disc. The next tier, discectomy, builds upon those bony skills by requiring the nerve root to be mobilized so that the annulus can be incised and the herniated disc removed. Unfamiliarity with endoscopic three-dimensional visualization could lead to accidental dural tears with each bite of the pituitary forceps. After this stage, more complex disc problems can be tackled, such as central herniations (requiring additional retraction), cranially or caudally migrated fragments (requiring more extensive bone work and altered angles of approach), and revision surgeries complicated by scar tissue and distorted anatomy. Surgeons should also be comfortable with right-sided approaches, which shift the orientation and instrument angle, an important challenge for right-handed surgeons lacking ambidexterity. Progression from ipsilateral laminectomy to bilateral decompression involves ensuring that the contralateral nerve root is decompressed (for instance, by removing the tip of the contralateral superior articular process), using a structured method for ligamentum flavum removal, and exercising caution around the midline fold of the dural sac, where tears can easily occur. In the fourth tier, paraspinal approaches require different incision plans and a detailed understanding of paraspinal foramen anatomy and vascularization. Finally, the pinnacle of these techniques is UBE-TLIF, which calls for precise incision placement to accommodate screw insertion, the ability to insert a cage through either an interlaminar or true transforaminal route, meticulous endplate preparation, and competence in performing full laminectomies with complete facetectomies (Fig. 5).

Cervical region and its generations

In the cervical region, UBE is a versatile and minimally invasive surgical approach. It is indicated for conditions such as spondylotic compression with or without myelopathy, foraminal stenosis, central and foraminal disc herniations, and multilevel stenosis. These pathologies are often associated with symptoms of nerve root compression or spinal cord involvement [7,27-29]. UBE offers several advantages over traditional techniques, including reduced muscle disruption, preservation of spinal motion, and lower rates of complications associated with anterior cervical discectomy and fusion [30-32].

The three main indications for specific procedures include laminectomy, ideal for multilevel cervical stenosis, especially in patients with hypertrophied ligamentum flavum or ossification of the posterior longitudinal ligament (OPLL), as it provides broad decompression with minimal disruption of the posterior tension band [19,33,34]; foraminotomy, commonly indicated for unilateral radiculopathy due to foraminal stenosis or disc herniations, providing direct decompression of nerve roots [27,35,36]; and discectomy, best suited for central or paracentral cervical disc herniations causing myelopathy or radiculopathy, offering effective decompression while preserving segmental motion [27,31,32].

Few articles explore the number of cases needed to achieve proficiency in the cervical region, but some experience is expected when tackling cervical cases. The CUSUM test revealed that proficiency is generally achieved after 20 cases of UBE cervical foraminotomy for a surgeon with at least 1 year of UBE experience [7]. The consistency of the surgical technique improves after this point, with reduced operation times and lower complication rates. For discectomy, particularly for treating central soft cervical disc herniations, surgeons achieve competency after approximately 15–20 cases [31]. These procedures involve greater precision in navigating the spinal cord, necessitating advanced endoscopic control. Laminectomy presents a steeper learning curve owing to its technical complexity, especially when addressing multilevel cervical stenosis or OPLL. The possible manipulation of the spinal cord can be a problem in this region, something that does not occur in the lumbar region. Studies suggest that surgeons should perform at least 30 simpler procedures, such as foraminotomies and single-level discectomies, before attempting laminectomy [18,32].

The most frequently reported complications in cervical UBE include dural tears (1%–5%), transient neurological deficits (1%–3%), and epidural hematomas [25,29,30,34]. These complications are more likely to occur early in the learning curve, with studies noting a higher incidence in the first 10–15 cases in a new surgeon's practice [7,32]. For this reason, initially, a novel surgeon should avoid complex cases, such as multilevel stenosis, severe cervical kyphosis, or segmental instability. Proper knowledge and real mastery of the technique are paramount. Surgeons should be familiar with the anatomical landmarks and endoscopic tools. Maintaining an irrigation pressure below 30 mmHg is essential to minimize the risk of dural tears and epidural hematomas [30,31].

As in the lumbar spine, progression in complexity should be methodical, as it is crucial to ensure both patient safety and successful outcomes (Fig. 6). The recommendation is to start with foraminotomy as the first tier in this region and as the 6th generation in our framework. Foraminotomy is a straightforward procedure and an ideal entry-level surgery for new UBE practitioners. It involves direct nerve root decompression without extensive exposure or manipulation of critical structures, such as the spinal cord. Studies have consistently reported reduced complications and shorter operative times in foraminotomies, making them an excellent starting point [7]. The natural transition should be toward discectomy. Once surgeons are confident in performing foraminotomies, they should transition to discectomy in cases involving central or paracentral disc herniations. These procedures require more precise handling of instruments near the spinal cord and dura and some nerve root manipulation. Proficiency is typically achieved in 15–20 cases, as noted in studies evaluating central disc herniation [27,31]. Finally, advancement to laminectomy should only be attempted after surgeons have mastered simpler techniques. The procedure requires intricate skills to achieve bilateral decompression through a unilateral approach while preserving cervical stability. It is suggested that surgeons perform at least 30 UBE cases, including a mix of foraminotomies and discectomies, before attempting laminectomy [18,19,25,33]. The complexity of laminectomy, combined with its potential risks (e.g., instability and kyphosis), makes it unsuitable for the early stages of training.

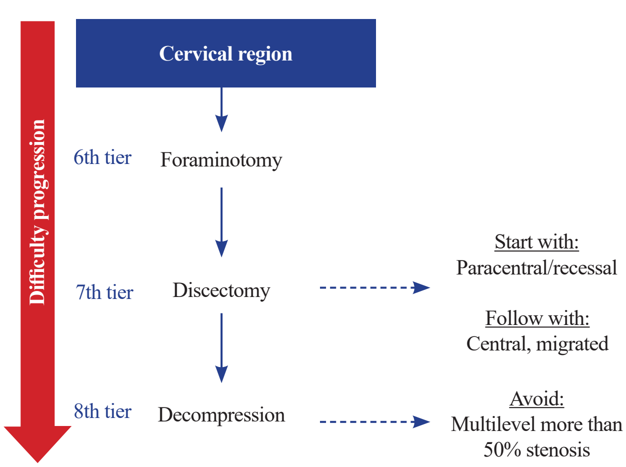

Fig. 6. Cervical tiers for unilateral biportal endoscopy difficulty progression.

Thoracic region and its generations

UBE in thoracic surgery has emerged as promising for addressing conditions such as thoracic OLF and thoracic disc herniation, mainly in the paracentral and foraminal locations. Current indications for its application include cases of thoracic myelopathy caused by OLF, single- or two-level thoracic disc herniation and selected instances of thoracic spinal stenosis. The procedure is particularly beneficial in patients without severe segmental instability, tuberous OLF, or extensive dural ossification [37-39]. However, selecting appropriate cases is critical to minimize complications. Fused-type or nodular OLF, centrally located calcified discs, and multilevel deformities (>3 levels) remain contraindications, especially for less experienced surgeons [39,40]. Advanced techniques such as the "outside-in" approach for *en-bloc* removal of OLF and the "floating" method for adherent lesions have been associated with superior safety profiles compared with traditional methods [38,40].

Tackling thoracic cases requires significant prior experience in lumbar and cervical endoscopic procedures. Kim et al. [39] emphasized the necessity of mastering lumbar endoscopic techniques before approaching the thoracic region because the thoracic spine presents smaller anatomical structures, higher sensitivity to compression, and greater technical demands. In the early phase of using the "inside-out" piecemeal approach, a 12.5% rate of spinal cord injuries was reported, underscoring the risks of limited experience. To safely perform thoracic laminectomies via biportal endoscopy, surgeons should have considerable expertise in endoscopic lumbar decompression. A stepwise approach to thoracic decompression is recommended, beginning with lateral OLF cases, then moving to extended and enlarged types, and initially avoiding nodular and fused variants [38-40].

Complications in thoracic UBE are relatively rare but include dural tears (6.3%–11.1%), spinal cord injuries (12.5% in early cases), epidural hematomas (6.3%), and insufficient decompression (up to 3.2%). Key factors influencing complication rates are surgeon experience, pathological complexity, and adherence to technical protocols. Prevention strategies can include preoperative planning, refinement of the technique (i.e., having experience), intraoperative monitoring, and irrigation pressure control [39,40].

In our proposed framework, surgeons should initially focus on thoracic laminectomies (9th generation) for OLF in single-level cases, avoiding dural ossification and severe adhesions (Fig. 7). Early career surgeons should defer laminectomies involving fused OLF until they are proficient in less complex thoracic cases and have substantial lumbar experience, as mentioned above. Finally, the transforaminal approach (10th generation) in the thoracic region introduces unique challenges owing to the limited working space and proximity to vital structures. This technique should only be attempted after mastering interlaminar thoracic decompression and gaining experience in advanced lumbar transforaminal surgery.

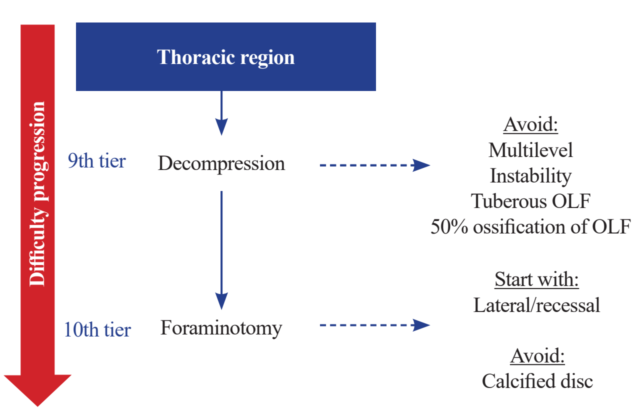

Fig. 7. Thoracic tiers for unilateral biportal endoscopy difficulty progression. OLF, ossification of the ligamentum flavum.

Conclusions

The proposed ten-generation progression for UBE offers a structured approach to mastering this innovative technique with the combination of already established educational methods. By aligning procedural difficulty with surgeon expertise, this framework can accelerate skill acquisition, optimize patient outcomes, and promote the widespread adoption of UBE. As the field evolves, this framework can serve as a foundation for training and standardization, ensuring that UBE achieves its full potential in minimally invasive spinal surgery.

Key Points

- The 10-tier framework proposes a structured 10-level progression for unilateral biportal endoscopy (UBE) based on surgical complexity.
- Skill building in UBE starts with basic lumbar procedures and advances to complex cervical and thoracic surgeries.
- The learning curve and mastery can be softened by combining different already established educational methods like virtual reality, simulations, cadaver labs, and mentorship.
- Competency-based progression emphasizes the attainment of defined surgical skills over a predetermined number of cases.
- Analytical tools such as cumulative summation methods can be employed to establish objective benchmarks for skill acquisition based on specific performance criteria.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Conceptualization: XASE. Methodology: XASE. Writing–original draft preparation: XASE. Writing–reviewing and editing: XASE, EGP, DJC. Visualization: XASE. Supervision: EGP, DJC. Final approval of the manuscript: all authors.

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