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A Systematic Review of Complications Associated with Initial Learning Curve of Endoscopic Spine Surgery Highlighting the Necessity of Introducing an Effective Fellowship to Train Competent Endoscopic Spine Surgeons

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Abstract

Background: There is an increase in interest of endoscopic spine surgery as an option of minimally invasive spine surgery. Complications associated with learning curve are a big obstacle to starting a successful endoscopic career. A good endoscopic spine surgery fellowship can mitigate the risk of practice in early phase in endoscopic spine surgery.

Methods: We conducted a systematic review in the PubMed database using the terms using three successive searches.10 articles met the criteria of learning curve in endoscopic surgeries evaluation of complications and operation timing. The most consistent parameters used in these studies to evaluate the learning curve were procedure time and complication rate as a function of chronologic case number, our analysis focused on these. The search strategy identified 10 original studies that included 618 endoscopic spine surgery procedures.

Results: In the 10 studies, total number of complications was 45 cases (7.2%). 33 cases (5.3%) occurred in the early phase of learning curve. The most frequent reported complications were incomplete decompression (18 cases, 2.9%), incidental durotomies (13 cases; 2.1%), nerve root injuries (11 cases; 1.77%), discitis (2 cases; 0.32% of complications) and hematoma (1 case; 0.16%). The operative time was observed to decrease throughout these case series with no general consensus of number of cases required to reach asymptote.

Conclusion: There is steep learning curve with high complications in the initial learning phase of endoscopic spine surgery. It is recommended to have an effective training or fellowship programme to train competent endoscopic spine surgeons.

Keywords: Endoscopic spine surgery • Endoscopy • Surgery education • Training program in surgery • Complications in endoscopic spine surgery • Learning curve in endoscopic spine surgery

Abbreviations: TELD: Transforaminal Endoscopic Lumbar Discectomy; TELF: Transforaminal Lumbar Foraminotomy; TE-LRD: Transforaminal Endoscopic Lateral Recess Decompression; IELD: Interlaminar Endoscopic Lumbar Discectomy; IE-LRD: Interlaminar Endoscopic Lateral Recess Decompression; LE-ULBD: Lumbar Endoscopic Unilateral Laminotomy for Bilateral Decompression; EELD: Extraforaminal Endoscopic Lumbar Discectomy; ICELF: Interlaminar Contralateral Endoscopic Lumbar Foraminotomy; PECF: Posterior Cervical Endoscopy Foraminotomy; PECD: Posterior Endoscopic Cervical Discectomy; AECD: Anterior Endoscopic Cervical Discectomy; TETD: Transforaminal Endoscopic Thoracic Discectomy; TE-ULBD: Throacic Endoscopic Unilateral Laminotomy for Bilateral Decompression

Introduction

With the evolution of endoscopic spine surgery as an option in minimally invasive surgery, there is an increasing number of endoscopic spine procedures performed to treat various spinal conditions. The steep learning curve was one of the reasons for the low overall pick up rate of endoscopic spine surgery among spine surgeons. There is paucity of literature to evaluate the initial complication rate during the early phase of learning curve of endoscopic spine surgery. The experts who practise uniportal and/or biportal endoscopic spine surgery from various centres around the world had set up fellowship program to fulfil the training requirements of budding endoscopic spine surgeon to mitigate these complication risks in early phase of endoscopic practice. Our objective in this review is to evaluate the most consistent parameters of the learning curve which were procedure time and complication rate. We also discussed the importance of endoscopic spine surgery fellowship. We propose various educational strategies and highlight the difficulties encountered by mentors and fellows in the process of gaining knowledge and skills in endoscopic spine surgery.

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Literature Review

Search strategy and criteria

We used the Cochrane methodology [1] to perform a systematic review of PubMed for the learning curve of endoscopic spine surgery. We used three successive searches: "Endoscopic Spine Surgery" (4221 results), "AND

complications" (reduced to 2301 articles), "AND learning curve" (reduced to 101 articles). A manual review of abstracts of 101 articles was performed. 85 articles did not describe procedures which used spinal endoscope and were excluded. 16 articles were reviewed in full, 6 articles which were describing techniques of tubular retractor with microendoscopic assisted decompression were excluded. 10 articles met the criteria of uniportal and biportal endoscopic surgeries evaluation of complications and operation timing in the initial learning curve were included in our systematic review [2-11]. None of the articles were case report (Table 1). The mean and median publication year was 2016. We included four Transforaminal Endoscopic Lumbar Decompression/Discectomy (TELD) studies, two Biportal Endoscopic Spine Surgery (BESS) studies, three Interlaminar Endoscopic Lumbar Discectomy (IELD) studies, one mixed TELD and IELD study in this review. No cervical or thoracic endoscopic spine procedures describing learning curve was found in our review. Of the 618 spinal endoscopic procedures included in this review, all were level IV evidence case series evaluating a retrospective cohort of patients operated at different time point of the performing surgeons (Figure 1).

Endoscopic learning curve parameters assessed were complication rate and operating time. In the 10 studies, total number of complications were 45 cases (7.2%) of which 33 cases (5.3%) occurred in the early phase of learning curve and 12 cases (1.9%) occurred at the later phase of learning curve. The most frequent reported complications were incomplete decompression (18 cases, 2.9%), incidental durotomies (13 cases; 2.1%), nerve root injuries (11 cases; 1.77%), discitis (2 cases; 0.32% of complications) and hematoma (1 case; 0.16%). 9 early revisions were reported of which 5 were done for dural tears, 4 were for incomplete decompression. 7 late revisions were done for recurrence of disc herniations. Joswig et al. [5] had a disproportionally high intraoperative conversion rate of 16/76 (21%) most of which were due to technical difficulties, while Passacantilli et al. [2] had 3/100 (3%) conversion due to technical difficulties. Various length of duration of procedures was reported as shown in Table 1. Due to heterogeneity of the 10 studies involved, we were unable to identify a conclusive number of cases needed to achieve asymptote for the learning curve. The operative time was observed to decrease throughout these case series prior to reaching asymptote with less variation in timing once asymptote of learning curve was reached.

Results and Discussion

An overall complication rate 7.2% was described in the 10 articles. We found a 3 fold risk in complication rate in the early phase of learning curve of endoscopic spine surgery as compared to late phase of endoscopic spine surgery. Joswig et al. described a high rate of open conversion of 16 out 76 cases (21%). Of the 16 open conversions, 11 cases were due to technical difficulties encountered in the early phase of learning curve [5]. Most their conversion was due to disorientation in anatomy and technical difficulties. The technical difficulties arise due to various factors such as:

- Unfamiliar endoscopic anatomy as endoscope has 30x magnification as compared to 2-10x magnification in microscope during spinal surgeries,
- Unfamiliar handling of endoscopic equipment as equipment was inserted through working cannula (biportal endoscopy) or working channel (uniportal endoscopy),
- Angular vision generated by lens more than 0 degrees. These technical difficulties led to higher rate of complications and conversion to open surgery attributed to the early phase of an endoscopic surgeon's learning curve. This could be mitigated by a structured fellowship training programme.

Fellowship is defined as "a program which provides advanced training in progressive levels of sub-specialization following completion of training in a primary specialty and if applicable a related sub-speciality. It designed to train physicians to provide unsupervised practice of medicine in a subspecialty" by the American Accreditation Council for Graduate Medical Education [12]. Spine

Table 1. Systematic review articles included in the evaluation.

Study	Intervention	Study Design	Sample Size	Learning Curve Findings
Bin Sun et al. [7]	TELD	Retrospective	60	Overall 7(11.7% complications, 6/30 in early phase and 1/30 in late phase of learning). 3 were dural tear, 2 residual disc and 2 discitis. 1 revision open discectomy for retained disc. 54 operations were needed to achieve satisfactory timing of <60 mins.
Hsu et al. [4]	TELD, IELD	Retrospective	57	2 complications of nerve injury 4 patients with insufficient removal All 6 cases (10.5%) had complications in early phase of learning period. 5 revision open discectomy with 3 done for insufficient disc removal and 2 for herniation.
Lee et al. [8]	TELD	Retrospective	51	17 cases in each of early, middle and late group. 4 failures (7.8%) in middle and late phase of learning curve. 2 minor complications occur in early and middle phase of learning period (3.9%) both complications were neuropraxia. No revision.
Ahn et al. [6]	TELD	Retrospective	35	First 15 cases compared with next 20 cases. Reduction of operating time to average time at 10th case. 4/15 complications (2 nerve root injury and 2 retained disc) in early group and 2/20 (2 nerve root) in late group of complications. No revision.
Choi et al. [3]	BESS	Retrospective	68	7 complications of 2 cases of dural tear, 4 cases of incomplete decompression, 1 nerve root injury. All 7 complications occurred in first 20 cases of BESS. No revision.
Park et al. [9]	BESS lumbar Decompression	Retrospective	60	Overall 6 /60 cases of complications. Early cases of first 30 cases had mean operative time of 105 minutes and 5 complications (20%) with 2 dural tears, 1 hematoma and 2 incomplete decompressions. Late phase of next 30 cases had mean operative time of 62 minutes and 1 complication of dural tear in the late cases. (3%). 1 revision for dura tear.
Joswig et al. [5]	IELD	Retrospective	76	Early group of 43 cases and late group of 25 cases. 11 out of 43(33%) in early group and 5 out of 25 cases (20%) in late group were converted to open microscopic discectomy. 1 conversion due to dural tear in early group and 2 conversion due to dural tear in late group. The rest of conversion was due to operation difficulty. Mean operative time is 65.5 +/-26.5 minutes in early group and 47.2 +/-17.9 minutes in late group.
Xu et al. [10]	IELD in L5/S1	Retrospective	36	3 groups of 12 patients each. No complications in all groups. Mean Operative time is 102.73 ± 17.16, 65.36 ± 11.45, 57.42 ± 7.57 in the 3 groups respectively.
Passacantilli et al. [2]	IELD L5/S1	Retrospective	100	First 30 cases mean operative time (52.5(30-75) mins and last 60 cases 27.5(15-40) mins. 0 complication, 5 recurrences, no mention of recurrence occurred at early or late group. All 5 recurrences underwent repeat IELD. 3 conversions due to technical difficulties
Yang et al. [11]	TELD	Retrospective	75	First 35 cases in early group , with mean operating time 95(85-110) minutes Last 40 cases were in late group with mean operating time 70(60-80) minutes. No difference in complication rate. 4 complications with 1 dural tear and 1 nerve root injury in each group. 1 revision in early group for dural tear in early group.

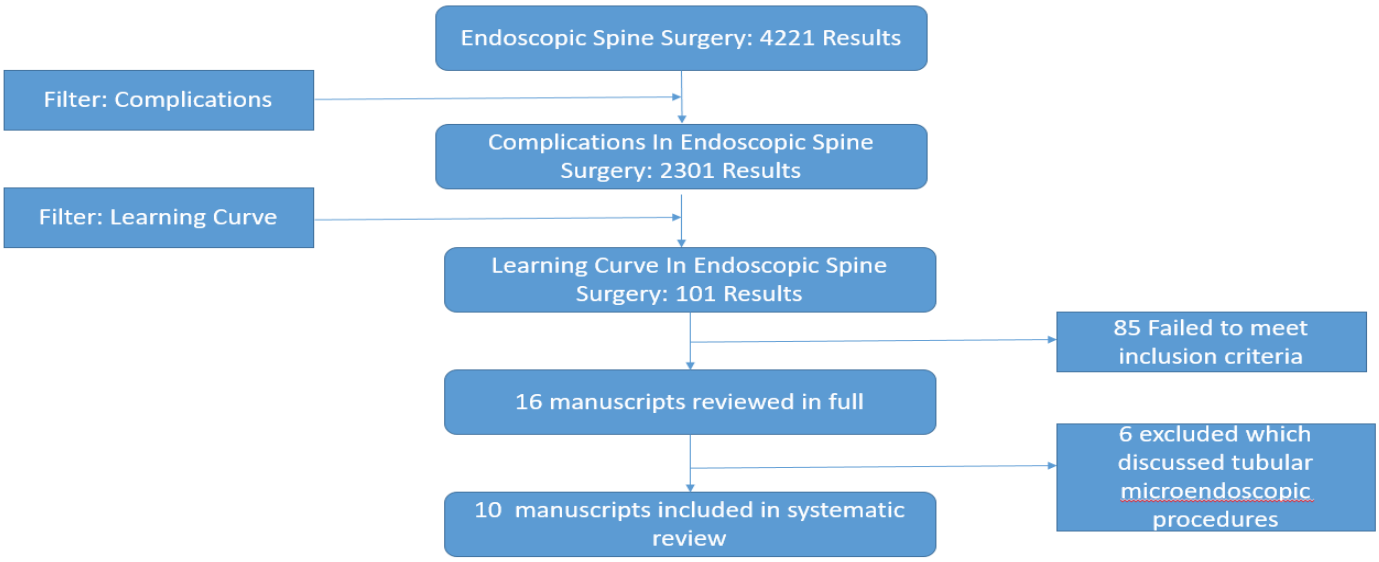

Figure 1. A flow diagram illustrates the search and selection process.

surgery fellows come from a diverse training background of orthopaedics and neurosurgery. Hence their curriculums have different focus in training [13,14]. Orthopaedic residents typically spent a large part of their surgical training in the placement of implants under open or fluoroscopic guidance and performing arthroscopic surgeries using 2 or more endoscopic portals during sports surgery postings. They gained operating experience using microscope in their hand and spine surgery rotations. While neurosurgical residents spent a large portion of their time in their surgical training performing handling delicate neural tissue under microscope and endoscope in surgeries. The orthopaedic and neurosurgery spine curriculums provide a good foundation of skills but usually do not provide enough clinical exposure for unsupervised practice of endoscopic spine surgery.

Prerequisites for Endoscopic Spine Fellowship

Proficiency in open spinal surgery

As a prerequisite for a successful career in endoscopic spine surgery, the trainees should be proficient in open spinal surgery before embarking on the fellowship of endoscopic spine surgery. There are several reasons for this suggestion:

- In case of a complex complication occurred during endoscopic spine surgery which cannot be resolved by using endoscopic spine surgical techniques, the surgeon might convert to open surgical repair.
- There are many areas of spinal conditions such as deformity, spinal fracture, tumors and trauma cases which require open surgery instead of endoscopic spine surgery. Surgeons who are trained in both endoscopic and open surgery can make better decisions for the patients based on their pathology rather than the surgeons' technical limitations.
- Endoscopic view of the spinal anatomy is often a tunneled vision with high magnification which makes it challenging for spatial appreciation of the anatomical regions and relationships. Hence a good background understanding of the spinal anatomy from open spine procedures experience is beneficial for endoscopic spine surgery.

Understanding the follow's local spinal healthcare system demands

Prior to application of endoscopic spine surgery fellowship, the trainee should evaluate his own local hospital practice. As majority of endoscopic spine surgery practice is addressing degenerative spinal diseases through decompression and fusion, the prospective fellow should project the proportion of degenerative spinal conditions in their practice upon return from the fellowship. Another consideration is whether the trainee's local population has the financial capacity to afford the relatively expensive equipment needed for endoscopic spine surgery. The fellow needs to understand what are the uniportal and/or biportal endoscopic equipment available in his native country before deciding which subtype of endoscopic practice is suitable for him. While it is possible to purchase or acquire new equipment after completion of fellowship, the time and financial constraints of his local healthcare environment in setting up an endoscopic practice may undermine the trainee's true potential. The benefits of endoscopic spine surgery have been proven in recent literature to provide equivalent or better outcomes to other form of minimally invasive spine surgery, hence if the local spinal healthcare system is favourable , it is worthwhile embarking on an endoscopic spine fellowship [15,16].

Finding the mentor (s) of choice

Many endoscopic spine experts are in a subspecialty of spine practice with a high percentage of endoscopic spine surgeries with few open spine procedures in their daily practice. While most if not all of the internationally renowned endoscopic mentors are proficient in English, the patients who interact with the fellow may not speak English or the fellow's native language. The trainee needs to find a mentor who can match the trainee's linguistic, academic and clinical expectations. It is important to communicate clearly with the mentor on the training objectives of the fellowship in terms of the academic and clinical expectations to ensure a smooth fellowship. Another consideration for the trainee is to decide whether he would like to engage a single mentor or a group of mentors in the same hospital for the duration of the fellowship. A single mentor fellowship would allow the fellow to develop a deeper understanding of the mentor's practice while a group practice would allow the fellow to rotate between different mentors providing a broader base and perhaps more general learning opportunities. While spinal fellowship in hospitals performing open spinal surgeries often sees a number of surgeons doing various types spinal surgeries in different days of the week, there is often fewer endoscopic spine surgeons in the endoscopic fellowship centre who operate on certain days of the week. The fellow may be engaged in academic research or providing consulting services in clinics during the non-operative days. An exchange program or elective posting can be potentially arranged on the days when the fellow has no clinical duties during the fellowship; such considerations should be discussed with the mentor in advance.

Clinical fellowship versus clinical observership program

Most countries allow clinical observership and research fellowships where there is an informal shadowing experience that enables participants to watch

procedures and surgeries; attend patient rounds and teaching conferences. Such clinical observership and research fellowships may have less medical licencing and visa requirements. However, for the case of medical registration as a clinical fellow, there are different medical licencing requirements in different countries. In some countries such as United States, Canada, Singapore and United Kingdom, there is a strict set of criteria in academic and clinical requirements in order to be qualified for medical registration as foreign clinical fellows. However once the foreign fellows are registered, they are able to participate in direct patient care and surgeries under supervision by mentors [17,18]. While some countries medical councils do not allow foreign fellows to perform clinical duties irrespective of the fellows' academic qualifications and clinical experience. Hence it is important for the prospective fellow to communicate his expectations with his mentors on the expected degree of hands-on experience in the surgical procedures prior to embarking this fellowship. There are other suggested prerequisites in order to demonstrate current readiness for application to an endoscopic spine surgery fellowship. A checklist for prerequisites is shown in Table 2.

Steps of Endoscopic Fellowship Competency Progression Model in Learning of Various Procedures

Due to the advancement of techniques, endoscopic optics and equipment, more complex degenerative cases are being treated with endoscopic spine surgery. There are 4 generations of endoscopic spine procedures in the evolution of endoscopic spine surgery described by Kim et al. [19]. The first generation focused mainly on transforaminal approaches [20]; the second generation introduced interlaminar approaches [21]; the third generation had included stenosis decompression, cervical and thoracic procedures and contralateral approaches [22-25]. While fourth generation involved spinal fusion procedures [19]. There are several considerations to be made in deciding the level of difficulty in endoscopic procedures (Figure 2):

- The ability in handling of endoscope and its related equipment.
- The amount of bone and soft tissue resection required for decompression.
- The operation to be performed at the cord level *versus* root level which has different implications on amount of neural retraction allowed during surgery.
- Traditional safe working corridor versus newly described approaches.

In the author's opinion, a progressive acquisition of knowledge and skills ensure safe surgery at various stages of the fellow's learning curve during the fellowship. We proposed an "Endoscopic Fellowship Steps of Competence Progression Model" in achieving endoscopic fellowship competency for the various endoscopic procedures described in the literature. This is in accordance to the abovementioned considerations in the levels of difficulty (Figure 2).

Primary step: Discectomy procedures

Transforaminal Endoscopic Lumbar Discectomy (TELD) and Interlaminar Endoscopic Lumbar Discectomy (IELD) [26-28] are the most commonly practice endoscopic procedures in primary step. It can be done under local anesthesia, regional anesthesia and less commonly general anesthesia. These procedures go through safe working corridors determined by the pioneers of endoscopic spine surgery, such as the Kambin's triangle in TELD and the axilla and shoulder region of neural elements in IELD [29,30]. These procedures tend to require less bone decompression and violation of facets [26-31]. There are controversies in the effects of various techniques such as inside-out, outside-in with fluoroscopic guided foraminoplasty and mobile outside for TELD. Similar debates were discussed for ligamentum splitting, ligamentum cutting and/or resection techniques in IELD. Different endoscopic experts adopt different techniques and produce good clinical results [27,32-34]. However, despite being the entry level endoscopic spine surgery, we should not underestimate the difficulties in performing TELD and IELD. There is inherent risk of recurrence and retention of disc in these procedures. There is natural anatomical constrain of iliac crest in TELD surgery at L5/S1. Other anatomical variations like the presence of a furcal nerve, a low lying exiting nerve root can complicate TELD with exiting nerve root neurological sequelae, incidental durotomies. These complications can lead to poor patients' outcome

Table 2. Prerequisite in endoscopic spine surgery fellowship. (ESS: Endoscopic Spine Surgery).

Preparation required prior to ESS fellowship	Remarks	Recommended timeline before fellowship
Completion of specialist accreditation	An ESS fellow should have completed or in the midst of completing an orthopedic surgery, neurosurgery or equivalent specialist accreditation in spine surgery prior to application for an ESS fellowship.	1-2 years
Forecast of percentage and spectrum of degenerative spinal conditions in the fellows' practice	Fellow should evaluate his role in his local practice, a forecast the percentage of degenerative spine cases he is going to manage after completion of ESS fellowship as the bulk of ESS surgeries are done on degenerative spinal conditions.	1-2 years
Evaluation of the future support of ESS practice in local hospital	Fellow should assess local resources available and potential vendors who are interested to provide the endoscopic related equipment required to support his practice. Alternatively, direct purchase can be made by hospital where he is employed in. Discussion with the local healthcare system should be made on whether they are keen to support the idea of spinal endoscopy in their system.	2 years
Completion of open spinal surgery training	Fellow who is comfortable with open spinal surgeries has the advantage of being able to manage complications arising from ESS by conversion to open surgeries. He can provide an open surgical approach to management of spine conditions which are contraindicated in ESS.	Any time before fellowship
Application for fellowship	After identifying the suitable mentor, fellows should make contact with the mentor through formal or informal inquiries for application of an ESS fellowship.	1-2 years
Host country's language , culture and social norms evaluation	It is imperative to consider the host country's language, cultural and social differences and how it affects the fellow's well-being while he is undergoing training overseas.	Before application of fellowship
Medical licensing and Work Visa Requirements	Each different host country has different medical licensing and visa requirements. Fellow needs to check that he can fulfil the requirements before confirmation of fellowship	Before application of fellowship
Funding and tuition fees	4 types of funding in fellowship: -Fully Funded fellowship which includes a stipend which can cover subsistence fee, duty allowance and housing allowance. -Partially funded fellowship -No funding and allowance -Fellow pays the mentor's institution a tuition fee	1-2 years
Accommodation	Some fellowship centres provide subsidized housing or hostel arrangements.	6 months to 1 year
Settling in arrangements for accompanying partner (s)	Visa, insurance and school fees for children etc.	1-2 years

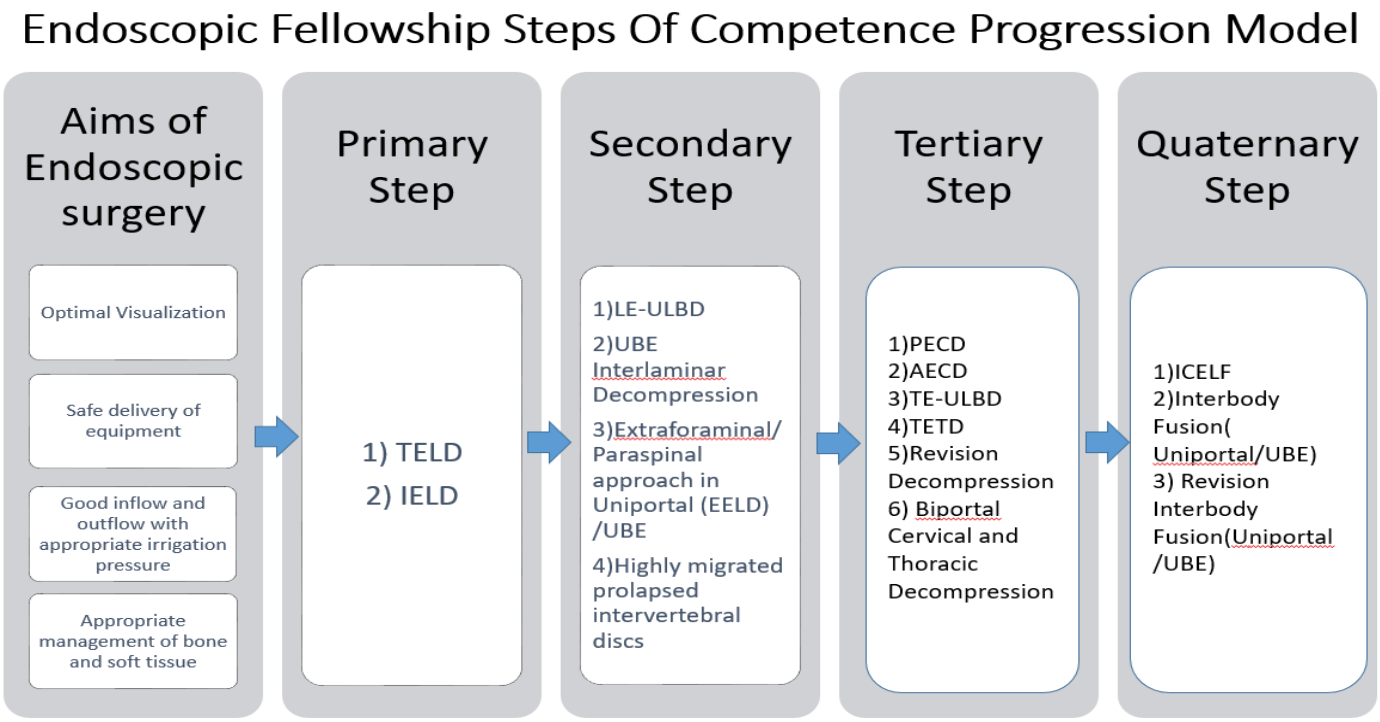

Figure 2. Endoscopic fellowship steps of competence progression.

[35-38]. Despite the fact that TELD and IELD surgeries required less technical steps , many experts feel that they are probably some of the most unpredictable and challenging surgeries among all the endoscopic procedures.

Secondary step: Decompression procedures from interlaminar or paraspinal approach and highly migrated prolapsed intervertebral disc

Lumbar Endoscopic Unilateral Laminotomy for Bilateral Decompression (LE-ULBD), Unilateral Biporal Endoscopic Surgery (UBE), extraforaminal/ paraspinal approach with uniportal or biportal endoscopic surgery techniques and highly migrated prolapsed intervertebral discs treated by TELD or IELD are next level of difficulty in the authors' opinion. These procedures tend to involve bony resection and handling of ligamentum flavum, with risks of over-resection of facet joints, incidental durotomies, neurological deficits and bleeding associated hematoma [39-42]. The pathological anatomy in these conditions such as enlarged facet osteophytes, spondylolisthesis with foraminal and extraforaminal stenosis , far out syndrome with transverse process and iliac crest compressing on exiting nerve root can be challenging obstacles to endoscopic experts. More bleeding from resected bone, radicular artery and its tributaries is an inherent obstacle in this group of procedures which can obstruct the endoscope view making the procedure more difficult.

Tertiary step: Cervical or thoracic decompression and revision endoscopic decompression

Uniportal spinal endoscopy techniques such as Anterior Endoscopic Cervical Discectomy (AECD), Posterior Endoscopic Cervical Foraminotomy and Discectomy (PECD), Thoracic Endsocopic-Unilateral Laminotomy and Bilateral Decompression (TE-ULBD), Transforaminal Endoscopic Thoracic Discectomy (TETD), revision discectomy and/or decompression are next level of difficulty [43-45]. UBE Cervical and Thoracic procedures are in this category as well. Cervical and thoracic surgeries are operating at spinal cord level pathologies; there is more significant risk of devastating neurology if any slip of working channel, endoscope and instruments or overzealous retraction by working channel. Hence great care and familiarity of endoscopic procedure and instruments are required before embarking on these procedures. [33-46]. For AECD, additional endoscopic equipment such as a side firing laser is required as intervertebral disc is removed in a perpendicular direction to the scope in a very limited space. TETD requires precise placement and docking of needle and obturator at a location closely related to the spinal cord, pleura, lung and the artery of Adamkiewiez [47,48]. Revision decompression can lead to confusion during the endoscopic procedure due to the disruption of familiar bony landmark from previous surgery. The presence of epidural scarring around the neural elements and inherent higher risk of instability in a revision setting are some of the other additional challenges faced by endoscopic surgeon [36,49].

Quaternary step: Interbody fusion and contralateral approach

Interlaminar Contralateral Endoscopic Lumbar Foraminotomy (ICELF) [40,50-52] and primary or revision Endoscopic Transforaminal Lumbar Interbody Fusion by uniportal or biportal approaches [53-55] are labelled as quaternary step for 2 reasons:

- These 3 types of procedures are operating in a less routine part of endoscopic anatomy with neural elements in close proximity. There is potentially higher risk in less experienced surgeons hands. For ICELF, there is a requirement of fine controlled endoscopic drilling of the lateral vertebral body, intervertebral disc space and foraminal bony elements which are in closely related to the exiting and traversing nerve root with an endoscopic view from the contralateral side [23]. This is a region of anatomy in which open and microscopic surgery does not have a clear view. Unfamiliarity in this part of anatomy can lead to higher risk of complications.
- As for interbody fusion in a primary or revision surgery, we need a myriad of additional equipment such as special design retractor, cage glider, expandable cage and special designed endoscopic osteotomes to complete the procedure. This equipment may not be readily available and endoscopic surgeons may need more experience in handling of this equipment during the procedure. Extra preoperative preparation of equipment and more training may be required before a fellow engaged in endoscopic fusion procedure. Availability of this additional equipment in the fellow's local practice setting can be a limiting factor in execution of these procedures.

Limitations of Current Endoscopic Spine Fellowship Programme

Framework for success of fellowship

Understanding the steps of difficulties in endoscopic procedure can help to design a better fellowship program with targeted goals to overcome these challenges for the fellows. There are several methods which can be used to acquire the required level of competence in order to perform these challenging endoscopic procedures.

Boot camp

A boot camp is a short duration training program conducted by different experts in which all the residents and fellows in their respective training institutions gathered under one arena to learn from the experts. These sessions consist of didactic teaching, clinical case scenarios discussions and skill workshops touching base with the fundamentals of endoscopic spine surgery. A randomised controlled trial done in North America showed that there is positive impact on the surgical performance of residents who attended the boot camp [56]. In South Korea, a similar type of boot camp usually held in the winter period every year for past 3 years, known as Korean Society of Endoscopic Spine Surgery (KOSESS) Winter Camp.

Cadaveric workshop and structured skilled laboratory curriculum

Cadaveric workshops are deemed to be effective in studies in promoting surgical skills as it is the closest scenario to actual operation [57]. Korean Society of Minimally Invasive Spine Surgery (KOSMISS), Global Spine and North American Spine Society have conducted pre meeting cadaveric workshops in their recent conferences. However a review of literature with a heterogeneous usage of validated tools for cadaveric training failed to show strong evidence effect of cadaveric workshop in competency and good outcomes in operating theatre [58]. Hence, it is essential to plan a structured skilled laboratory curriculum for each individual cadaveric stations which outline the steps of endoscopic procedures in order to provide clarity of the surgical objectives to the trainees. This strategy optimises the training experience of participants in cadaveric workshop.

Simulation training

While Cadaveric workshop is the closest scenario training to real life surgery, it is costly and logistically challenging. Simulation training with 3D model is a viable alternative to practice handling of sharp equipment such as endoscopic drills, punches and forceps under endoscopic vision (Figure 3). As the 3D model is portable, it can be used in the office setting or operating room setting to mimic the real life case scenarios (Figure 4). Such training is

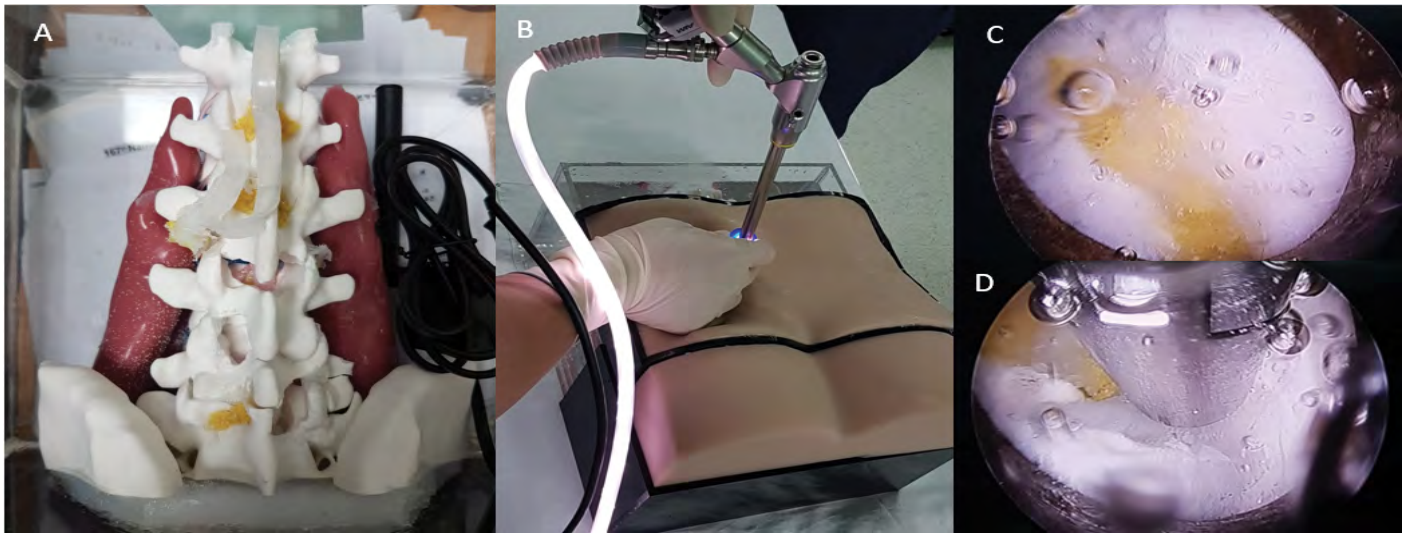

Figure 3. Simulated 3D bone and soft tissue model. Images courtesy of Dr. HS Kim in design and execution of the simulated endoscopic spine surgery. Figure 3A showed 2D printed bone model which mimics in one to one ratio with actual human spine. Figure 3B showed silicon construct which is used to allow simulation of docking and manipulation of endoscopic equipment. Figures 3C and 3D showed operative video of lamina and flavum with forceps touching the inferior articular facet of the simulated model.

Figure 4. Simulation training for transforaminal endoscopic lumbar discecotmy. With a portable 3D model, one can set up simulation training in the operating room or in the office setting to practise endoscopic techniques.

helpful for spatial orientation and coordination of endoscope and endoscopic equipment in both uniportal and biportal endoscopic surgery. One of the early challenges of trainees attempting biportal endoscopic surgery is for the viewing endoscope on one hand to "find" the working instruments on the other hand to set up a "meeting position". It is not uncommon for surgeons who are not familiar with arthroscopy to be facing this scenario of failure to set up a meeting position. Another common error for the beginners is inadvertent damage of endoscopic lens by endoscopic drill. Such technical skills acquisition can be done with simulation model at a lower cost than a Cadaveric workshop.

Observation/Participation/ Performing surgeries and clinics under supervision

Live surgeries are essential for a competent surgeon to make wise intraoperative decisions to complete safe and effective surgery. The advantage of endoscopic spine surgery is clear visualisation of the procedure through operative video and intraoperative fluoroscopic images. It is important for fellows to take note of the handling of equipment by the experts in addition to viewing the operative video to understand the technical handling of the endoscopic equipment (Figure 5). A sample of technical handling assessment checklist is shown in Table 2. The best learning experience is obtained from performing part of the surgery under supervision of endoscopic expert. However, this form of coaching is subjected to the fellowship host countries medico legal climate, medical council registration rules and prevailing practices. Fellows should attend clinic sessions with their mentors to understand the indications, contraindications and to take part in preoperative planning in endoscopic spine surgeries during these clinic sessions.

Academic research and participation in endoscopic conferences

An endoscopic fellowship is a symbiotic relationship for the mentor and the fellow in terms of clinical and academic activities [59,60]. Most of the endoscopic fellowship expects significant research output from the fellow. It is a form of "give back" to time spent by mentor in coaching the fellow. Research is a way of progressive learning and feedback on the trainee understands of the topic

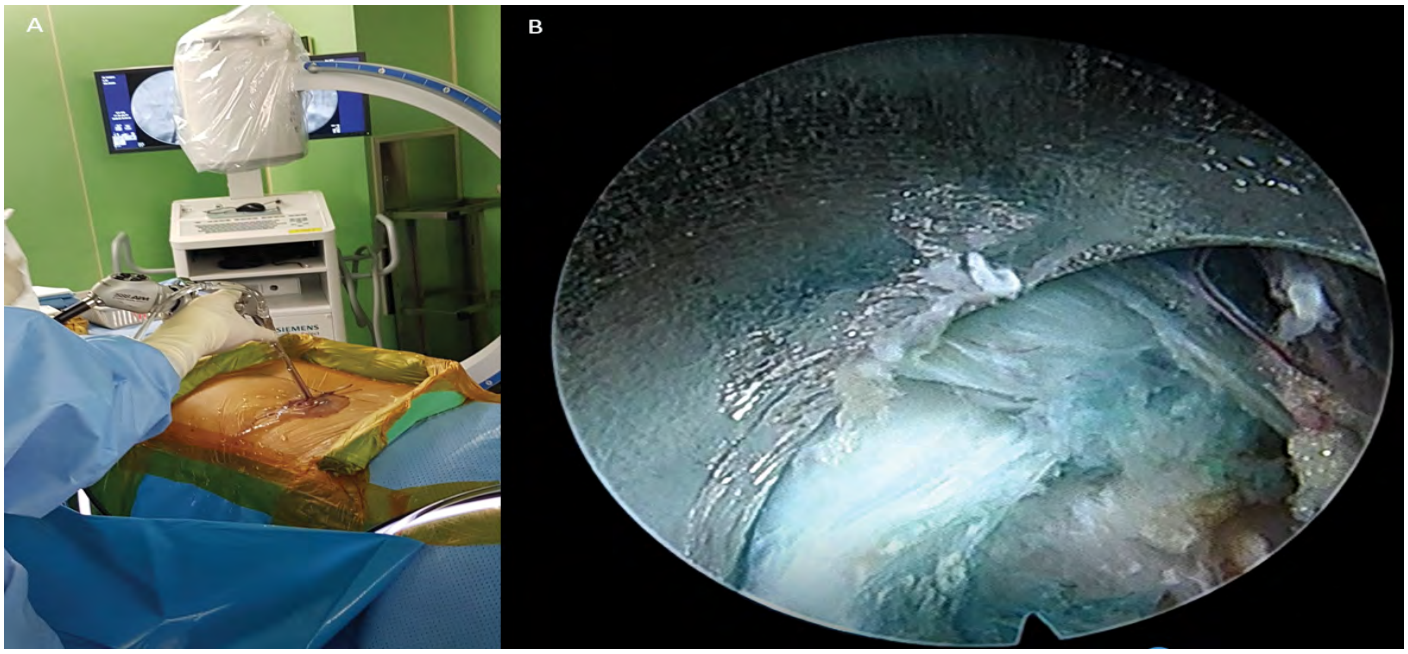

Figure 5. This showed external hand position and intraoperative video of interlaminar endoscopic lumbar discectomy of left L4/L5. It is important to appreciate the hand position while appreciating the effect of these endoscopic manipulation have on the intraoperative video magnified field of bone and soft tissue.

Table 3. Summary table of fellowship program (ESS: Endoscopic Spine Surgery, UBE: Unilateral Biportal Endoscopy).

List of recommended activities during endoscopic spine fellowship	Ideal Outcomes Of Activities	Recommended Duration
Boot Camp	Understanding the principles of ESS, discussion for clinical scenarios, complications management and understand the tips and tricks from ESS experts	2-7days
Academic Conferences	Poster and oral presentations	5-10days
Research Activities	Publication of one or more research paper(s) to understand the ethics, workflow in publication and to critically evaluate ESS treatment methods.	Most days of the fellowship
Simulation training	To practice the steps of endoscopic procedures, gain familiarity of using endoscopic equipment under magnified endoscopic vision. To be comfortable in using working portal instruments to safely set up a meeting position with endoscope in UBE.	3-5 sessions
Cadaveric Workshop	To practise the haptic feedback, hand eye coordination and to appreciate endoscopic anatomy under endoscopic vision. To practise the steps of endoscopic procedures.	1-3 sessions
Live Surgeries	Observing or performing live surgeries under the supervision of an endoscopic mentor. Case logs should be documented for end of posting evaluation.	Most days of the fellowship
Clinic Sessions	To understand the indications, contraindications and perform preoperative planning in the clinic settings	Most days of the fellowship
Elective Posting	Arrange for visitation to other experts near the fellow's training vicinity if the fellowship program allows.	1-2 weeks (optional)
Diploma /Examination	A structured curriculum for knowledge acquisition and clinical skills evaluation should be developed in near future for assessment in budding endoscopic spine surgeons. It provides feedback on the proficiency of the fellow and identify gaps in knowledge and clinical skills.	If not available , one can consider alternative assessment (Table 4)

Table 4. Sample clinical fellowship assessment tools table (ESS: Endoscopic Spine Surgery).

Assessment Methods	Fellow's preparation	Mentor's preparation
Surgical Case Logs	Document the nature of operation, learning points and the fellow's role as a surgeon, assistant or observer	Review fellow's surgical log regularly to assess competency and consider arranging extra teaching sessions for deficient techniques.
Monthly Progress Evaluation	Document the academic and clinical activities in a month	Regular feedback on fellow's performance and evaluate whether the fellow has met his objectives of the fellowship.
Journal Clubs	Critical review of relevant articles and provide updates on current knowledge gaps. Practice oral presentation skills	Appraise the fellow's oral presentation skill Sharing of knowledge and expert opinion
Clinical Case Presentations and Discussions	Prepare interesting case presentations or complex case management strategies	Discuss rationale of management, tips and tricks of ESS in these interesting cases
Research Output Evaluation	Prepare a list of articles under preparation, submission, acceptance and publication status Presents abstracts in academic conferences Design interesting basic science and clinical research	Provide mentorship and guidance Review the written articles
Clinical Oral Viva	Review the current literature and read up on the various techniques of ESS	Oral viva can be given as an ad hoc basis during clinics and surgery or a scheduled oral viva in regular intervals
Paper Examination	Review the current literature and read up on the various techniques of ESS	In an ideal setting if there is a designed curriculum or diploma program , a written test would be ideal to ensure fellow's knowledge is up to date
Surgical skills evaluation	Preparation for various ESS steps of competence progression (Figure 2)	Critically appraise and discuss the surgical skills deficiency of the fellow.

and a method for evaluation of the clinical results of the various endoscopic techniques [61]. Active participation in endoscopic related conferences is also important to keep abreast of the latest knowledge in the field of endoscopy. We suggest a list of activities to enhance the fellowship experience which is summarised in Table 3.

Diploma and examination

A diploma program and an exit examination is a common practice in other endoscopic related specialties [62,63]. However, a diploma program had not been implemented in endoscopic spine surgery. Endoscopic spine surgery diploma curriculum and its examination would be helpful in assessment of competency in fellows who had completed endoscopic spine surgery fellowship. It would also be helpful assessment for the medical communities and the patients on who is the fellowship trained endoscopic surgeons in their respective countries. However the negative effect of having such a rigorous diploma program and examination is that may discourage established spine surgeons from switching their microscopic minimally invasive practice to endoscopy as it takes great humility and discipline to be examined as students or fellows in a new subspecialisation. As a diploma program is not available, we suggest a list of alternative assessment methods for mentors to consider in evaluation of the fellows performance which is summarised in Table 4.

Mentorship beyond the completion of spinal endoscopic fellowship

The end of an endoscopic spinal fellowship is the beginning of a lifelong relationship between the fellow and their mentor. The mentorship continues way beyond the fellowship duration, including and not limited to involvement in research and education collaborations, practical advice for complex case scenarios, revalidation and mutual visits in exchange of new ideas in techniques and insights. A successful fellowship and continual mutual support will add value to a global network of endoscopic spine surgeons in this growing field of spinal surgery [64-66].

Conclusion

There is a trend of higher complication and longer operation time during early phase of learning curve in endoscopic spine surgery. Good guidance from fellowship mentor is recommended to overcome the steep learning curve. It is evident that the differences in outcome can be significant between proficient and inexperienced surgeons. We suggest a stepwise approach in progression in delivery of progressively more challenging endoscopic procedures during the fellowship. This stepwise acquisition of knowledge and skills can be achieved structured teaching in simulation trainings, cadaveric workshop, live surgeries and various assessment tools moderated by the endoscopic mentors. Despite the allure of endoscopic surgery, it is important for the fellows to be competent with open procedures in order to resolve complications arising from endoscopic spine surgery with open conversion and manage challenging cases which required open surgical intervention.

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