

Review

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Review

Evolution, Current Trends and Latest Advances of Endoscopic Spine Surgery: A Narrative Review

Sharvari Gunjotikar ¹, Malcolm Pestonji ², Masato Tanaka ^{1,*}, Tadashi Komatsubara ¹, Shashank J Ekade ¹, Ahmed Heydar ¹ and Huynh Kim Hieu ¹

¹ Department of Orthopedic Surgery, Okayama Rosai Hospital, 1-10-25 Chikkomidorimachi, Minami Ward Okayama, Okayama, 702-8055, Japan; sharvarigunjotikar@gmail.com, tanaka0896@gmail.com, t.komatsubara1982@gmail.com, drshashankjekade@gmail.com, dr.a.heydar@gmail.com, huynhkimhieumd@gmail.com

² Department of Orthopedic Surgery, Golden Park Hospital and Endoscopic Spine Foundation India, Vasai west, Maharashtra, India 401202; malcolmpestonji64@gmail.com

* Correspondence: tanaka0896@gmail.com; Tel.: +81-86-262-0131.

Abstract: The aging of the population in developing and developed countries has lead to a significant increase in health burden of spinal diseases. These elderly patients often have a number of medical co-morbidities due to aging. The need for minimally invasive techniques to address spinal disorders in this elderly population group cannot be stressed enough. Minimally invasive spine surgery (MISS) has several proven benefits such as minimal muscle trauma, minimal bony resection, lesser post-operative pain, decreased infection rate and shorter hospital stay. Over the last 40 years, constant efforts are being made to develop newer techniques of spine surgery. Endoscopic spine surgery is one such subset of MISS which has all the benefits of modern MISS. Endoscopic spine surgery initially was limited only to treatment of lumbar disc herniations. With improvement in optics, endoscopes, endoscopic drills and shavers, irrigation pumps, there has been a paradigm shift. Endoscopic spine surgery can now be performed with high magnification thus allowing its application not only to lumbar spinal stenosis, but also to spinal fusion surgeries, cervical and thoracic pathology as well. There has been increasing evidence in support of these newer techniques of spine surgery. For the purpose of this review, we studied current available literature and outlined the historical evolution of endoscopic spine surgery, the various different endoscopic systems, and techniques available and the current applications of endoscopic techniques as an alternative to traditional spinal surgery.

Keywords: endoscopic spinal surgery; full endoscopy; biportal endoscopy; lumbar endoscopy, thoracic endoscopy; cervical endoscopy

1. Introduction

With advancements in medical care and increased life expectancy of the aging population, the global burden of spinal disease has increased [1]. Spine related disorders significantly affect the quality of life (QOL) and ability to perform activities of daily living among the elderly [2]. Elderly patients with spinal disorders often suffer from numerous co-morbidities and medical problems further complicating surgical treatment and functional outcomes [1,3,4]. In an attempt to decrease the morbidity associated with conventional open spine surgery, numerous advances have been made in the field of minimally invasive spine (MIS) surgery. MIS surgery has several advantages such as minimal soft tissue trauma, lesser blood loss, decreased infection rates, earlier rehabilitation, shorter hospital stay, and better functional outcomes [5]. Endoscopic spine surgery is an evolving subset of MIS surgery with ever growing indications [6]. With development of specialized instrumentation and high resolution imaging, endoscopic spine surgery initially limited to lumbar discectomies, can now be used to treat a wide range of spinal pathologies such as spinal stenosis, instability, thoracic and cervical myelopathy, infections, intradural tumors, etc. [7–9].

With this review, we aim to outline the historical evolution of endoscopic techniques for spine surgery, the present applications of endoscopic spine surgery in clinical practice and the latest advances in this field.

2. Evolution of Endoscopic Techniques for Spine Surgery

The earliest account of percutaneous decompression techniques dates back to Kambin in 1973 and Hijikata in 1975 who described their technique of percutaneous nucleotomy which was an indirect non visualized decompression through the postero-lateral approach using fluoroscopy. Kambin used Criag cannula (5.5mm) and Hijikata used a 2.6mm cannula respectively [10,11]. The next advancement to percutaneous nucleotomy was the addition of endoscopes and in 1983 Kambin described his technique of percutaneous arthroscopic discectomy[12] and subsequently, in 1990, he described a triangular safe zone bordered by the exiting root anteriorly, the traversing root medially, and the superior endplate of the lower lumbar vertebra inferiorly [13]. The description of this radiographic safe working zone allowed the introduction of larger instruments and working channels in closer proximity to the foraminal pathology without injuring the nerve root and thus led to further advancements in the field of endoscopic spine surgery.

In 1997, Foley described his technique of mircroendoscopic discectomy which to date is one of the most popular techniques of discectomy. He used a 25 degree scope through a 16mm tubular retractor to achieve decompression for far lateral disc herniations [14,15]. In the same year, the Destandau’s Endospine technique was introduced by Dr J. Destandau, based on the principle of laparoscopic triangulation between an endoscope and suction with working instrument. The system is composed of three tubes: one for the endoscope, one for aspiration and the largest one for standard surgical instruments [16,17]. In 1990s, Yeung developed an operating spine scope with a working channel and introduced beveled and slotted cannulas and subsequently allowed for direct visualization surgical removal of disc material and foraminal decompression (foraminoplasty) through of a uniportal approach [18,19]. They called their technique the “inside out technique” of endoscopic spine surgery where the working cannula was placed inside in the intervertebral disc [20]. Subsequently, in an attempt to avoid irritation of the nerve root in cases of foraminal stenosis Thomas Hoogland described the “outside in technique” where the working cannula was placed in the neural foramen after widening it using reamers [21]

Even though transforaminal endoscopic techniques were popular, there were several technical challenges for transforaminal access at L5 - S1 level owing to anatomical constraints such as high iliac crest, large L5 transverse process, large facet, narrow disc space and neural foramen [22,23]. In an attempt to overcome these technical difficulties Choi et al described the the technique of percutaneous endoscopic inter-laminar discectomy using a rigid working channel endoscope [24]. Irrespective of the technique used, the above endoscopic spine surgeries are performed through a single incision involving light source, irrigation, and instrumentation. Despite use of a superior imaging, visualization is restricted and technical difficulties may be encountered by surgeons, which are of relevance in severely stenotic canals or in cases requiring bilateral decompression [25]. Unilateral biportal endoscopic spinal surgery (UBE) or percutaneous biportal endoscopic decompression (PBED) [26] is the combination of integrated open and endoscopic spinal surgery, which can lessen the impact of the limitations. Unlike other endoscopic techniques, this technique utilizes 2 independent portals, one for introduction of the endoscope and other for introduction of surgical instruments.

Table 1. Historical review of endoscopic technique.

Year	Author	Technique described
1973	Kambin (10)	Percutaneous nucleotomy with Craig cannula (5mm) Fluoroscopy guided without visualization

1975	Hijikata (11)	Percutaneous nucleotomy (2.6mm cannula) Fluoroscopy guided without visualization
1983	Kambin (12)	Percutaneous arthroscopic discectomy
1997	Foley (14)	Microendoscopic discectomy
1999	Yeung (18)	YESS - inside out technique
1999	Destandau (16)	Destandau's Endospine technique
2005	Hoogland (21)	Transforaminal Endoscopy - Outside in technique
2006	Choi (24)	Interlaminar approach for L5-S1 level
2016	Eum et al (26)	Unilateral Biportal Endoscopy (PBED)

3. Lumbar Spine Endoscopy

3.1. Microendoscopic Discectomy and Decompression

Microendoscopic discectomy is a minimally invasive surgery technique that was initially described in 1997 [14]. It allows surgeons to work with two hands through a small-diameter, operating table-mounted tubular retractor and a 25 degree endoscope. [14,15]. Compared to conventional open discectomy, microendoscopic discectomy(MED) has several advantages such as lesser blood loss, cosmesis, shorter hospital stay, and early return to work [15]. A study of 150 consecutive patients treated with MED in 2005 confirmed these findings [27]. MED technique has been used not only for paracentral disc herniations, but also for all types including far lateral, cephalad, caudal migrated, and recurrent disc herniations [28,29].

Due to the advantages of MED, in 2002, Khoo and Fessler modified the MED technique and used it to treat 25 patients with LSS [30]. Compared to the open technique, microendoscopic decompression group had statistical decrease in operative blood loss, postoperative narcotic requirement, and length of hospital stay (42 hr versus 94 hr) [30]. Even today, Microendoscopic discectomy and decompression are one of the most commonly performed techniques for treatment of lumbar disc herniations and lumbar spinal stenosis.

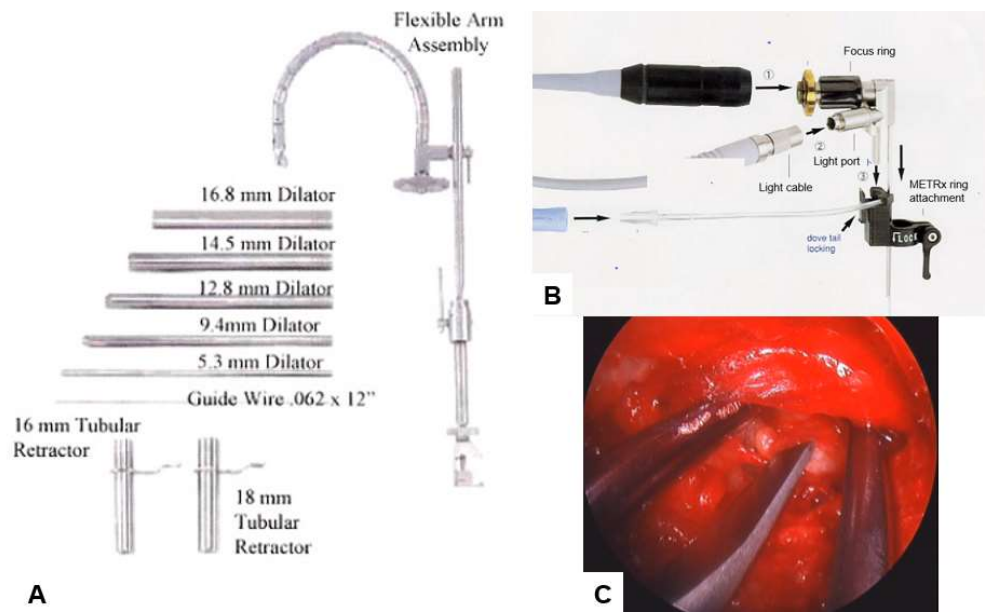


Figure 1. MED, A: METRx system C: Scope and attachment, D: Endoscopy image.

Table 2. Surgical results of microendoscopic discectomy and decompression.

Author	Sample	Approach	Follow up	Outcomes	Complication
Perez-Cruet 2002 [27]	150	Paramedian	12 months	Mean operative time (min) 97 Mean hospital stay (hours) 7.7 (range, 2–24) Mean time to return to work (days) 17	Dural tears 8/150 (5%) recurrence 4/150 Pseudomeningocele 1/150 (0.7%) Surgical site infection 1/150 (0.7%)
Khoo 2002 [30]	25 vs 25 open	Paramedian	12 months	Lesser blood loss 44ml for med vs 193 ml Shorter hospital stay 42 hours vs 94 hours	Additional fusion surgery 0% vs. 12% Transfusion 0% vs. 8% Dural tear 16% vs. 8%
Ikuta 2005 [31]	47 vs 29 microdiscectomy	Paramedian	22 months	Rate of recovery 72% (improvement in JOA score) (38/47)	Higher complication rate compared to microdiscectomy
Wu 2006 [32]	873 Vs 358 open	Not specified	28 months vs 31 months for open	Earlier return to work Shorter hospital stay Shorter operation time Lesser blood loss	35/873 for MED vs 19/358

Author	Sample	Approach	Follow up	Outcomes	Complication
				Lesser analgesic need	
Fukushi 2015 [33]	58 vs 39 open	Midline	42 months	Similar improvement in JOA and similar patient satisfaction	Higher rate of infection,
Wu 2020 [34]	82 vs. 52 Full endoscopy	Paramedian	20 months	Similar improvement in VAS for leg pain Higher VAS for low back pain and ODI	Dysesthesia 0% vs. 1.9%, Dural tear 2.4%vs. 1.9%, Urinary retention 1.2% vs. 0%, Total 3.85% vs. 3.66%
Iwai 2020 [35]	60 vs. 54 Microendoscopic	Paramedian	3 months	Shorter operating time but longer hospital stay compared to biportal endoscopy. Similar VAS/NRS in both groups	Dural tear 5.6% vs. 1.8% Hematoma 3.3% vs. 13.0%
Ito 2021 [36]	139 vs. 42 Biportal Endoscopy	Paramedian	6 months	Similar improvement in VAS for low back pain and leg pain, OD	Dural tear 5.8% vs. 4.7%, Hematoma 3.6% vs. 0%, Re-operation1.4% vs. 0%

3.2. Destandau’s Endospine Technique:

This technique requires use of a specialized system called the Destandau Endospine System (Karl Storz, Tuttlingen, Germany), which comprises an endospine tube, trocar, and working insert. The working insert comprises four ports—4-mm endoscope (0°), 4-mm suction cannula, 8-mm for the

working instrument, and nerve root retractor [37] There are numerous applications of the Destandau system ranging from degenerative spinal conditions to intradural tumor surgery [21]



Figure 2. instruments of Destandau's endospine technique.

3.3. Transforaminal Endoscopy

Transforaminal approach was the first approach which was used by the pioneers of full endoscopic spine surgery techniques[38] The key transforaminalecompression is safe docking of the endoscope, which requires careful analysis of preoperative radiologic imaging to evaluate the angle of approach required to retrieve fragment and understand the anatomic constraints in the transforaminal approach.(38)two popular techniques are the “inside out technique” [20] by Yeung and the “outside in technique” described by Hoogland. (21) Although it was initially believed that transforaminal approach has several limitations , literature suggests that this technique can be applied successfully to treat migrated disc herniations and foraminal pathology such as foraminal disc herniations and foraminal stenosis. (39,40) Literature suggests that challenging cases like highly migrated disc herniations can be operated by using the transformational endoscopic lumbar discectomy (TELD) by performing partial resection of the pedicle and enlargement of the foramen. (41) TELF can be used to treat foraminal stenosis while maintaining favorable long-term outcomes without the need for fusion in the vast majority of patients. (42) Several cadaveric studies also showed confirmed feasibility and efficacy of percutaneous endoscopic lumbar foraminoplasty/ TELF.(43,44)

When used for revision spine surgery, TELF and TELD are associated with minimal blood loss, lesser scar tissue formation and similar operating time compared to primary spine surgeries (45,46 In addition to other advantages of this technique such as shorter operation time, minimal blood loss and less muscle trauma, there are several published reports of transforaminal endoscopic spine surgery performed in awake patients under local anesthesia (47,48). Therefore, transforaminal endoscopic spine surgery is a viable surgical treatment option for patients with severe medical co-morbidities who are medically unfit to undergo surgery under general anesthesia.

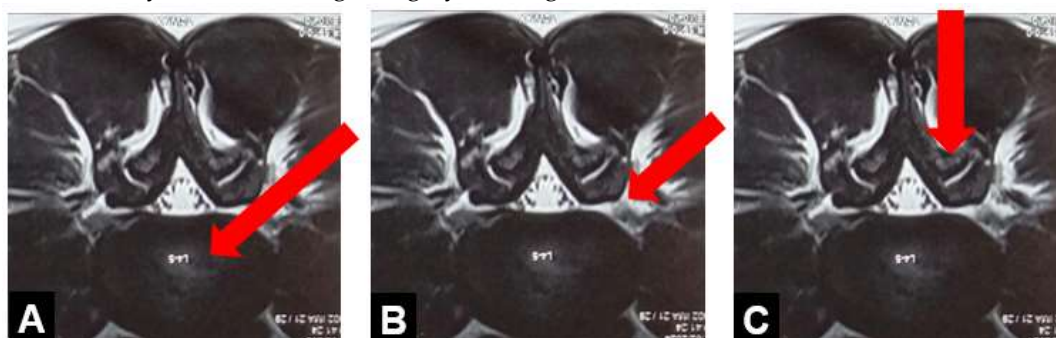


Figure 3. Three kinds of endoscopic approaches, A: Inside out approach - Starts from the disc to the epidural space、 B : Outside in approach - Starts from the epidural space, with or without foraminoplasty、 C: Interlaminar approach.

3.4. Interlaminar Endoscopy :

3.4.1. Interlaminar Endoscopic Lumbar Discectomy (IELD)

Due to technical difficult of using the transforaminal approach at L5-S1 level due to anatomical constraints, the inter laminar approach was advocated (24). Due to similar orientation compared to conventional posterior decompression techniques, the inter laminar approach though initially described for L5-S1 level was popularized for surgical treatment of lumbar canal stenosis (LCS) even at higher lumbar levels.

The patients undergoing IELD have significant advantages such as lower immediate postoperative back pain, shorter operation time, and rapid return to work.(49) Reuten et al followed up 178 patients who underwent either interlaminar endoscopic lumbar discectomy (IELD) or microsurgical discectomy and concluded that Full-endoscopic surgery is a sufficient and safe alternative to microsurgical procedures with minimal soft tissue trauma. (50)

The Interlaminar approach can also be used to treat Lumbar spinal stenosis. Lumbar endoscopic - unilateral laminotomy and bilateral decompression (LE-ULBD) when compared to microscopic ULBD showed comparable clinical and radiological outcomes. The endoscopic approach might further minimize tissue injury and enhance post-operative recovery. (51,52) McGrath et al in a similar study found that Lumbar endoscopic unilateral laminotomy for bilateral decompression is a safe and effective surgical procedure with favorable complication profile and patient outcomes.(53).

3.4.2. Percutaneous Biportal Endoscopic Discectomy and Decompression (PBED)

The PBED technique, involves using one portal for the endoscope and the other for introduction of instruments for performing decompression. In recent years, this technique of spinal surgery has gained tremendous popularity due to the advantages of familiarity of surgeons to posterior approach, free dexterity and use of conventional instruments used for open spine surgery. (54,55,56). It is generally believed that UBE surgery has the advantages of a wider field of vision, minimal muscle damage and faster recovery. (57) The learning curve of this technique is relatively shorter than that of uniportal full endoscopic surgery, which is another advantage of the UBE technique. (58)

UBE discectomy is a good treatment choice for lumbar disc herniation.(59) The Biportal endoscopic technique can also be used to treat foraminal pathology such as foraminal stenosis and far lateral disc herniation by using the extraforaminal technique described by Ann.(52)

A number of studies have compared the intra-operative and post-operative outcomes following PBED. Compared to ILED, PBED has superior results such as shorter operation time, better central canal decompression.(60) and less violation of the facet joints. (61) PBED has also demonstrated favorable clinical outcomes for revision surgery such as lower postoperative pain and has outcomes comparable to primary PBED, thus suggesting advantage of PBED for revision spine surgeries. (62)

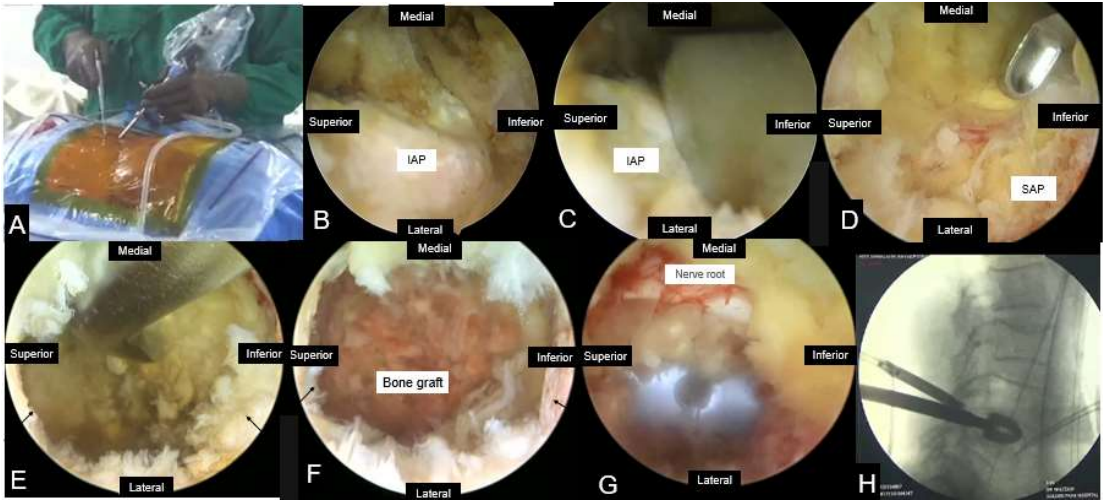


Figure 4. Unilateral Biportal Endoscopic Transforaminal Lumbar Interbody Fusion. A:Scopic and Instrument portals. B:Endoscopic view after soft tissue dissection. C:osteotomy of inferior articular process (IAP) D:Resection of tip of superior articular process (SAP) E&F:removal of disc and preparation of disc space. G: Endoscopic view showing insertion of cage.H:Final position of cage. This step is followed by insertion of Percutaneous Pedicle screws under fluoroscopic guidance.

Table 3. Clinical Results of Unilateral Biportal Endoscopy.

Author	Study type	Sample	Diagnosis	Follow up (Months)	Operation time (minutes)	Complications
Eum et al (2016) [26]	Retrospecti ve	58	LSS	13.8	68.9 ± 16.1	13.8%; post-op headache(3),dural tear (2),transient numbness (2), epidural hepatoma (1)
Choi et al (2016) [63]	Retrospecti ve	68	LDH(25), revision(3) stenosis(3 9),synovia l cyst(1)	NR	68.2±23.7	10.3%;dural tear(2),nerve root injury(1),incompl ete decompression(4)
Kim et al (2018)[64]	Retrospecti ve	60	LDH	12.6	70.15 ± 22.0	5%, incomplete decompression (3)
Ahn et al (2018)[55]	Retrospecti ve	21	Foraminal stenosis (11), foraminal LDH(9),A SD(1)	14.8	96.7	4.8%;dural tear (1)
Kim and Choi (2018)[65]	Retrospecti ve	105	LSS	14	53 ± 13.5	2.9%;dural tear (2), epidural hematoma(1)

Author	Study type	Sample	Diagnosis	Follow up (Months)	Operation time (minutes)	Complications
Akbary et al (2018)[66]	Retrospective	30	Lateral recess+foraminal stenosis	5.67	102.5 ± 43.66	0%
Pao et al (2019)[67]	Retrospective	81	LSS	8.6	NR	8.6%;dural tear(4), transient motor weakness (1), inadequate decompression (1),epidural hematoma(1)
Wang et al (2023)[68]	Prospective	70	LDH	24	NR	0%

3.4.3. Endoscopic Lumbar Interbody Fusion

Current literature in endoscopic fusion can be broadly divided into transforaminal lumbar interbody fusion by the Kambin triangle ventral to the facet joint with or without foraminoplasty, transforaminal lumbar interbody fusion through posterolateral approach by uniportal or biportal endoscopy, through the resected facet joint and endoscopic-assisted lateral lumbar interbody fusion.(7) The technique of transforaminal lumbar inter body fusion via the Kambin’s triangle can be used as an alternative technique for spinal fusion in patients with severe medical comorbidities as it can be done under local anesthesia. (69) The technique is based on the principle of indirect decompression and has several advantages such as short operative time, minimal blood loss and ability to perform visualized preparation of the end plates. However, the disadvantages are possibility of injuring the exiting nerve root and radiation exposure.(70)

Full endoscopic lumbar interbody fusion (FELIF) has the advantage that it allows direct decompression of pathology with minimal invasive technique.(70) FE-PLIF via the inter laminar approach is known to have outcomes compared to other popular minimally invasive techniques like MIS TLIF with minimal surgical trauma.(71).

Endoscopic lumbar interbody fusion using percutaneous unilateral biportal endoscopic technique can achieve direct neural decompression similar to conventional open surgery and can be an alternative to minimally invasive LIF surgery for treating degenerative lumbar disease. However, long-term follow-up and larger clinical studies are needed to validate the clinical and radiological results of this surgery.(54)

According to a recent meta-analysis, UBE-TLIF was superior to MIS-TLIF in terms of intraoperative blood loss, duration of hospital stay, VAS score for low back pain and ODI score, but the operative time was longer than MIS-TLIF group. There were no significant differences between the two groups in terms of total complication rate, modified Macnab grading criteria, fusion rate, VAS score of leg pain, lumbar lordosis, intervertebral disk height.(72)

4. Thoracic Spine Endoscopy

Initially limited to the lumbar spine, in recent years there has been a steady and significant interest in its applications to cervical and thoracic spine pathologies. With instrumentation and technology spinal endoscopy is now a viable alternative to traditional open surgery that avoids the

risks & complications associated with open thoracic spine surgery. The sizes and the number of working channels are the parameters typically used to categorize the different types of spinal endoscopy and much of the capabilities of these different systems, and their inherent advantages and disadvantages, are predicated upon these two factors(73). The techniques most commonly employed are full endoscopy (transforaminal & posterior percutaneous), micro-endoscopy and bi-portal endoscopy.

4.1. Full Endoscopy

The following full endoscopic classifications are currently recommended by the AO Spine group(74).1) Transforaminal endoscopic thoracic discectomy (TETD),2) Thoracic endoscopic unilateral laminotomy for bilateral decompression (TE-ULBD), 3) Transpedicular endoscopic surgery. The most commonly employed approaches are transforaminal and interlaminar. The majority of reports describe a transforaminal approach for disc prolapse with interlaminar access used for the treatment of significant canal stenosis(75). The results of endoscopic discectomy in the thoracic spine have been satisfactory suggesting possibility of large scale role of minimally invasive endoscopic techniques in the surgical management of thoracic disc herniations including soft as well as calcified discs. (76,77)

Use of endoscopy for other spinal disease such as infection and tumor have been reported in several publications(78). Yang et al.(79) in a relatively large series of patients with tuberculosis, described use of percutaneous decompression with fusion with allograft followed by percutaneous pedicle screw fixation. They reported excellent outcomes with 96% of patients achieving acceptable fusion. The increasing number of publications in the last three years suggests that full endoscopy is the technique of choice in many centers and will become the universal standard of patient care(75).

4.2. Micro-Endoscopy

The thoracic micro-endoscopic discectomy (TMED) technique is a modification of the lumbar micro-endoscopic technique that has been used with success to treat stenosis as well as disc herniations(80). This method has been implemented successfully to treat lateralized and central soft thoracic disc herniations causing radicular and myelopathic symptoms(81).

The TMED technique has a number of advantages over other traditional techniques for thoracic discectomy and include the following: avoidance of entering the thoracic cavity, minimal osseous and ligamentous removal, maintenance of disc integrity, avoidance of the need for thoracic fusion, and avoidance of extensive posterior muscle dissection(81). TMED is a safe effective treatment for surgical removal of herniated thoracic intervertebral discs and allows for a posterolateral approach to thoracic disc herniation without entry into the chest cavity that consistently gives access to the majority of the canal while requiring only a minimal amount of bone removal. (80,82)

4.3. Bi-Portal Endoscopy (UBE)

Thoracic laminectomy has traditionally been considered gold standard for the treatment of thoracic OLF and stenosis. Post surgery back ache, paraspinal muscular atrophy and instability are known complications of traditional open surgery often requiring revision and fusion. The clinical outcomes of a conventional technique for thoracic OLF or thoracic spinal stenosis are frequently unsatisfactory and comorbid(83).

To address these issues, unilateral bi-portal endoscopy (UBE) techniques for thoracic laminectomy have been developed and published, demonstrating various advantages over conventional thoracic laminectomy, and reporting competent clinical results(84,70). The main advantages of this approach are the independence of scope and instrument control, as well as greater degree of freedom for positioning of the instruments(58). Although UBE has grown in popularity in recent years, thoracic ULBD via UBE is technically difficult (86).

UBE decompression is a viable treatment alternative which is capable of achieving satisfactory clinical results in patients with thoracic OLF.(87) While treating thoracic OLF or thoracic spinal

stenosis, UBE decompression technique with unilateral approach and bilateral decompression appears to be safe and effective. (86) Although thoracic ULBD by UBE is not currently the standard treatment for thoracic OLF or thoracic spinal stenosis, this technique has the potential to be more widely used in the future(87).

5. Cervical Spine Endoscopy

The anterior percutaneous cervical discectomy was the prototype of cervical endoscopic surgery.(88) Subsequently many variations & techniques have been developed to deal with cervical spine pathologies. Anterior cervical discectomy and fusion (ACDF) has long been considered the gold standard for cervical disc disease.(89)

Posterior full endoscopic cervical foraminotomy and additional discectomy showed similar clinical outcomes to conventional ACDF(90). Cervical motion was preserved better in posterior full endoscopic cervical foraminotomy and discectomy(91). Patients who underwent endoscopic surgery had less blood loss, shorter operation times, and shorter hospital stays than those treated with conventional open foraminotomy(92). Cervical myelopathy which was earlier thought to be a contra-indication for endoscopic surgery is now routinely treated with UBE and large diameter full endoscopes.

Some studies have demonstrated that UBE laminectomy may be considered an excellent surgical alternative to treat cervical stenosis without the development of iatrogenic kyphosis(93). It represents an effective method with excellent neurological and radiological outcomes with less soft tissue invasion, which translates into dramatically less postoperative axial pain and maintained postoperative cervical lordosis(93). Wang et al concluded in their study that UBE and PE (percutaneous posterior endoscopic discectomy) were both safe and effective in the treatment of cervical spondylotic radiculopathy and were characterized by minimal trauma, no adverse impact on cervical stability and few complications(94). It is safe to say that cervical endoscopic surgeries have evolved and are no longer limited to dealing with just single level disc disease.

5.2. Endoscopic Anterior Cervical Discectomy and Fusion

Ahn et al reported 5-year follow-up outcomes of anterior full endoscopic discectomy for soft disc herniation and showed comparable results with conventional ACDF(95). Recently Endoscopic ACDF has also been performed but no concrete data is currently available proving its efficacy.

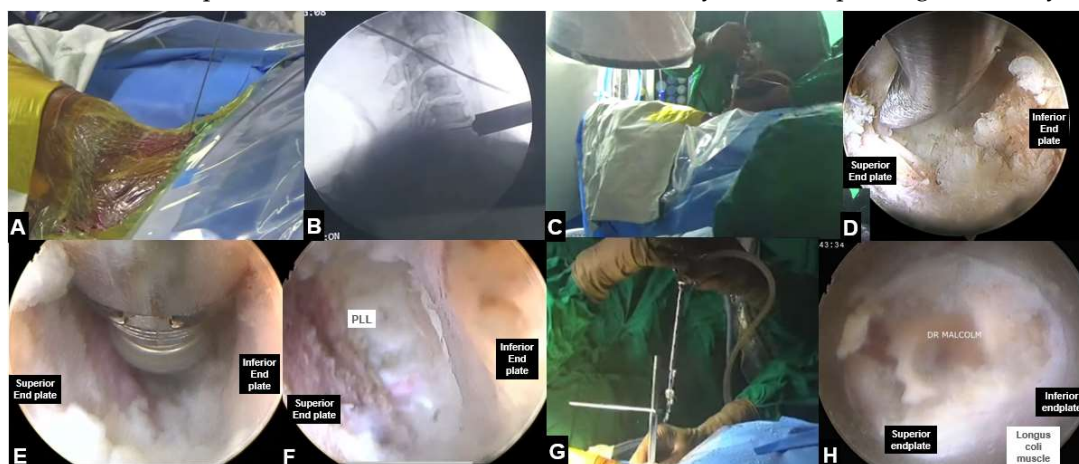


Figure 5. Endoscopic Anterior Cervical Discectomy and Fusion, A: Intra-operative level marking . B&C: Docking over C6-C7 disc space D&E: Endoscopic view showing removal of disc and preparation of disc space. F: Endoscopic view showing complete removal of disc and adequate endplate preparation. G: Introduction of cage F: final position of cage.

5.3. UBE Cervical Foraminotomy and Laminectomy

Some studies have demonstrated that UBE laminectomy may be considered an excellent surgical alternative to treat cervical stenosis without the development of iatrogenic kyphosis(77). It represents an effective method with excellent neurological and radiological outcomes with less soft tissue invasion, which translates into dramatically less postoperative axial pain and maintained postoperative cervical lordosis(77). Wang et al concluded in their study that UBE and PE (percutaneous posterior endoscopic discectomy) were both safe and effective in the treatment of cervical spondylotic radiculopathy and were characterized by minimal trauma, no adverse impact on cervical stability and few complications(78). It is safe to say that cervical endoscopic surgeries have evolved and are no longer limited to dealing with just single level disc disease.

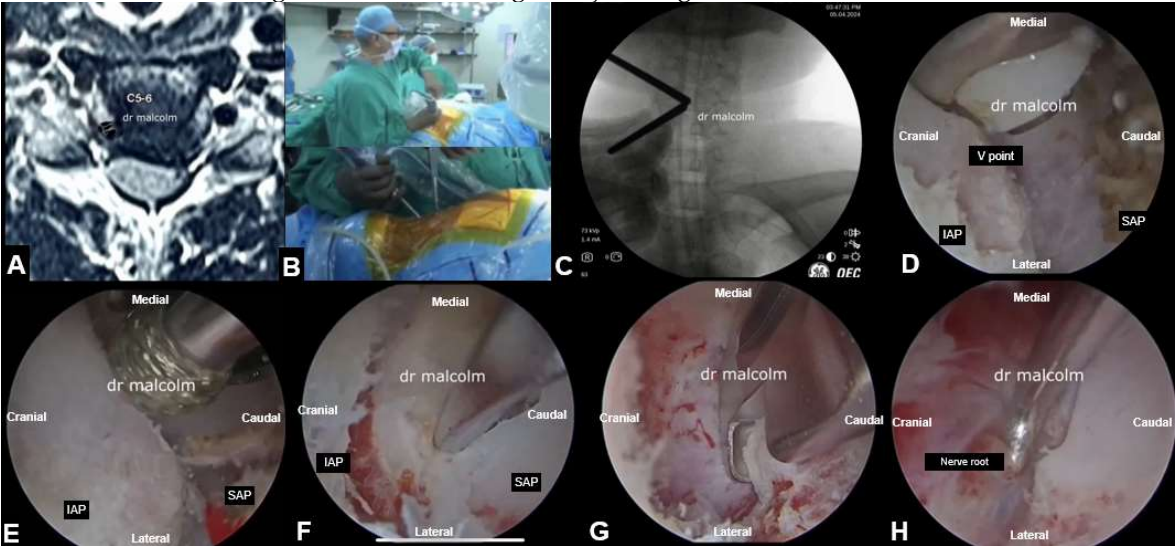


Figure 6. UBE Cervical foraminotomy and Laminectomy, A: Axial section through C5-C6 disc showing left sided disc osteophyte complex with impingement of left C6 nerve root. B: Intra-operative surgical view. C: Intra-operative fluoroscopic view showing targeting of V point i.e. junction of inferior articular process (IAP) with superior articular process (SAP) D: Endoscopic view showing identification of V point. E: Beginning of decompression by burring of IAP F,G: Resection of IAP and SAP with kerrison Ronguers H. Final image showing adequate decompression of the nerve root.

Table 4. Clinical Result of Cervical Spine Endoscopy.

Author	Sample	Approach	Follow up	Outcome	Complication
Fontanella (1999)[96]	296 (273 anterior,23 posterior)	Anterior, posterior	12 months	97% success at 1 year; average surgical time 25 min	Nil
Ahn (2005)[97]	111	Anterior	49 months	Excellent/ good outcome in 80%	Persistent radicular pain in 1 patient 1 patient required ACDF
Lee (2007)[98]	116	Anterior	36 months	87 % had good outcomes	2 patients ACDF 2 patients repeat endoscopy

Author	Sample	Approach	Follow up	Outcome	Complication
					1 patient - posterior fixation
Reutten (2009)[99]	60	Anterior	24 months	96% - good clinical outcome	2 patients - progressive neck pain 2 patients - radicular pain 4 patients - ACDF
Yang (2014)[100]	84	Anterior 42 Posterior 42	18 months	Shorter operating time for anterior approach Shorter hospital stay for posterior approach	1 Neurological deterioration 1 Hematoma - 1 Re-operation -1 post-operative headache -
Oertel (2016)[101]	43	Posterior	6 months	82% regained full arm strength; mean one level operation time 77 min	1 haematoma, 1 triceps paresis

6. Latest Advances

6.1. Navigation

Debilitating consequences for patients can occur to damage to important structures such as nerves and blood vessels . Navigation systems that use real-time images improve surgical accuracy [103,104]Using O-arm, a high-quality computed tomography (CT) scan can be performed. Surgeons can perform intraoperative three-dimensional (3D) anatomical mapping in real time by integrating it with a real-time anatomical tracking tool[105]. Spine surgeons initially use navigation systems for percutaneous pedicle screw fixation, but nowadays, navigation systems can be used for various surgical procedures.

[106] Some examples of such applications in the field of endoscopic spine surgery are shown in the figures below.

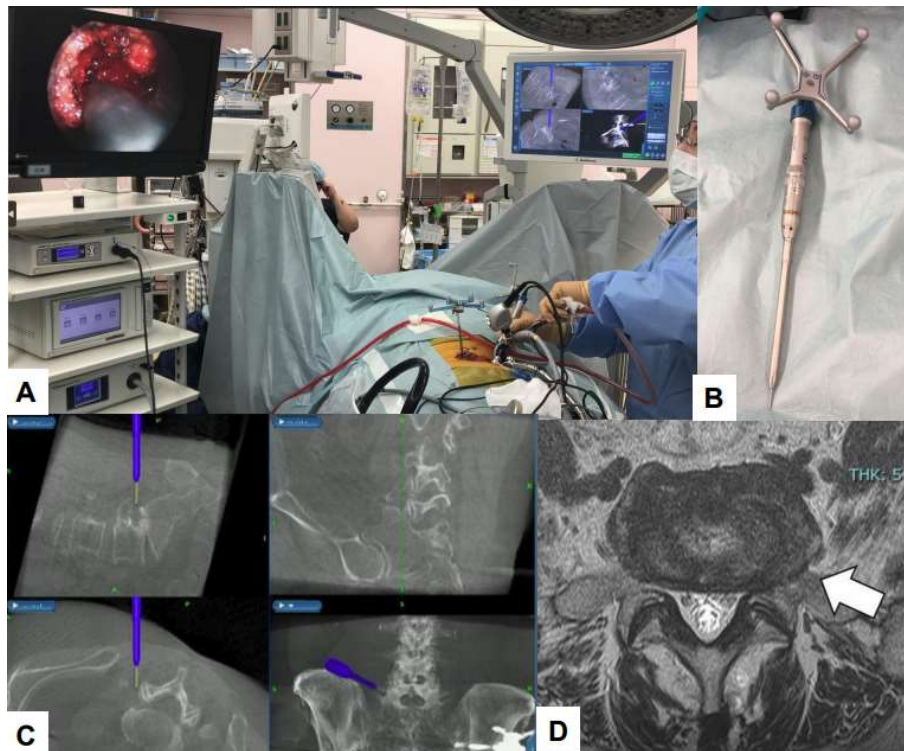


Figure 7. C arm free MED posterolateral, A: Intraoperative image, B: Navigated high speed burr, C: Navigation monitor, D: Preoperative MRI, A white arrow shows left L5/S1 lateral lumbar disc herniation.

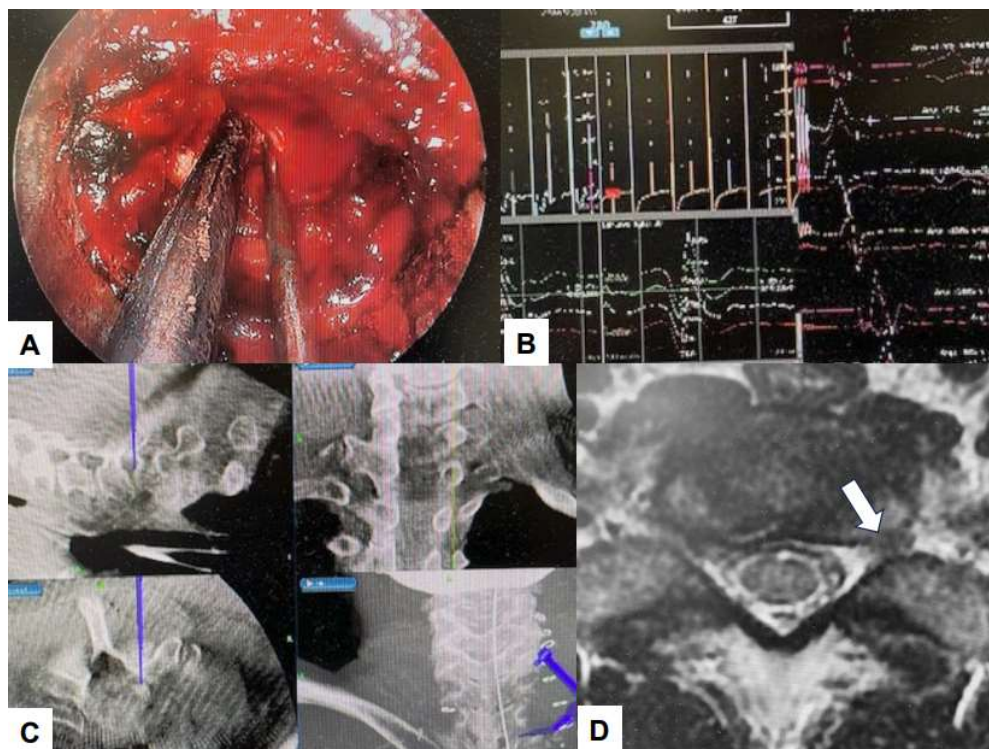


Figure 8. C arm free cervical endoscopic keyhole foraminotomy, A: Endoscopy image, B: Neuromonitoring, C: Navigation monitor, D: MRI. A white arrow shows cervical disc herniation.

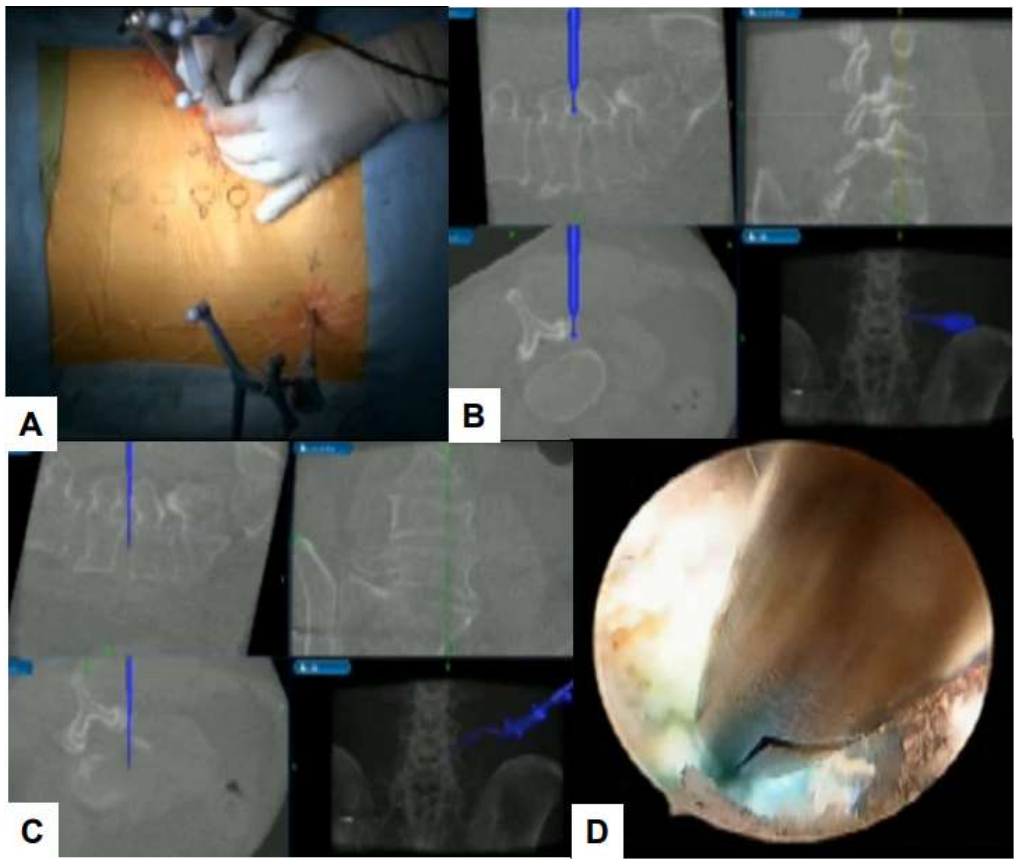


Figure 9. C arm free lumbar transforaminal discectomy, A: Endoscopy image, B: Foraminoplasty with a navigated high speed burr, C: Navigated approach to the disc, D: Endoscopy image.

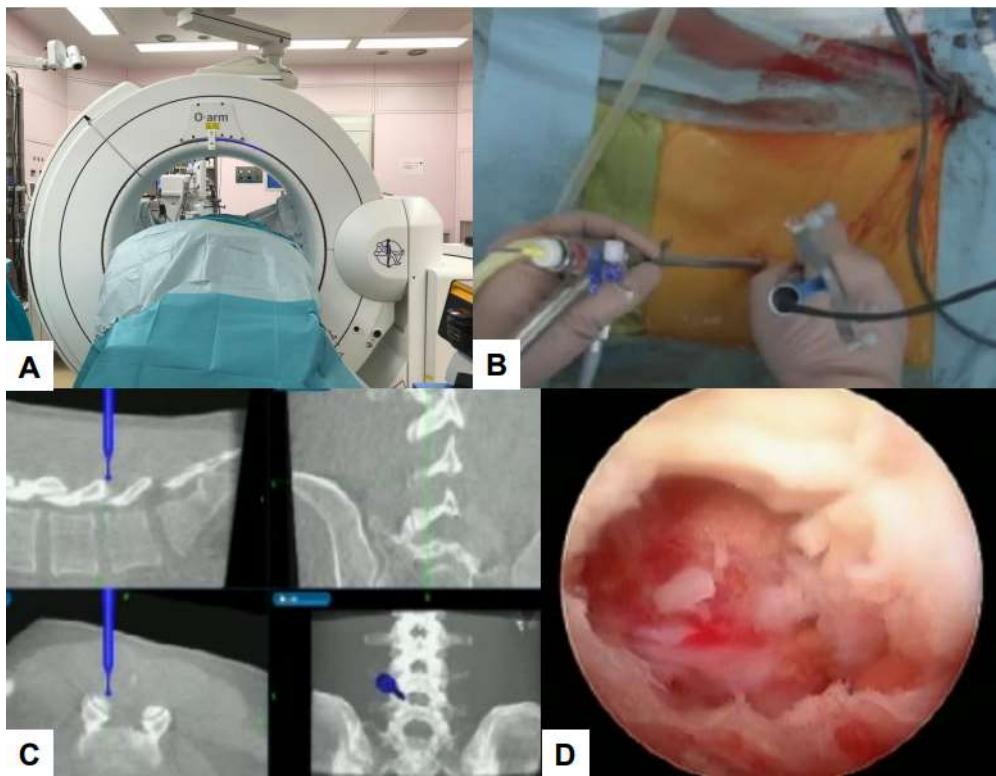


Figure 10. C arm free UBE, A: O arm, B: Intraoperative image, C: Navigation monitor, D: endoscopy image.

6.2. Ultraresolution and Three Dimensional Endoscopes

Resolution refers to the number of pixels a display holds. For instance, 2K (Full HD) has a resolution of 1920×1080 pixels, whereas 4K (Ultra HD) has a resolution of 3840×2160 pixels. The advantage of higher resolutions is their capacity to depict patient tissues with greater precision.(106) Also, the current 2 dimensional endoscopic spine systems lack depth perception causing unfamiliarity with surgical anatomy and may cause devastating complications . (107) Three-dimensional (3D) endoscopic equipment provides clear views of surgical anatomy, such as exposure of dura and nerve roots.(108) Using a 4K ultra-resolution endoscope, structures such as foraminal ligaments, which are difficult to observe with conventional microscopes, can be easily identified(109). Furthermore, accurate perception of the degree of stenosis and disc protrusion using 3D visualization could reduce surgical uncertainty, followed by better decompression of neural structures and better surgical outcomes(107).

6.3. Robot-Assisted Endoscopic Surgery

Robot-assisted spine surgery with systems such as Mazor X (Medtronic Inc., Dublin, Ireland) and ROSA (Medtech S.A., Montpellier, France) is being performed especially for pedicle screw placement with several advantages (110,111) This technology enables surgeons to enhance their manual dexterity with greater control and maneuverability through even a small portal, reducing physiological tremors(112). Robot-assisted spine surgery can provide accurate and safe guidance for discography in the initial steps of percutaneous endoscopic cervical discectomy(113) or PELD(114). Robot assistance was recently used to perform full endoscopic lumbar discectomy (115). Thus, robot assisted surgery may be used to perform other techniques of spine endoscopy in the near future.

7. Conclusion

The field of Endoscopic spine surgery has been developing rapidly over the last 40 years. Though initially limited to lumbar discectomies, Endoscopic spine surgeries have been used to treat cervical and thoracic stenosis as well. Significant advances have been made in the optics, resolution and instrumentation of endoscopic spine systems and hence the indications for this subset of minimally invasive spine surgeries has increased. However, the data regarding the applications to spinal conditions other than degenerative pathology such as spinal tumors, infection and trauma is lacking.

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