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REVIEW

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Thoracic endoscopic surgery: advantages and limitations

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Abstract

Background Thoracoscopic spine surgery is a form of minimally invasive spine surgery primarily used to treat thoracic spinal disk herniation and stenosis via endoscopic discectomy and decompression techniques, respectively. In contrast to the lengthy recovery time and related risks of an open approach, this minimally invasive technique primarily attempts to limit tissue trauma while maintaining therapeutic efficacy. Thoracoscopies and video-assisted thoracoscopy surgery were first developed in the early 1990s. Larger surgical instruments and improved access to foraminal pathologies were made possible because of Kambin's triangle. This triangle zone is formed by the exiting root anteriorly, the traversing root medially, and the superior end plate of the lower lumbar vertebra inferiorly. With the development of high-quality video imaging, small endoscopes, and modified new instruments, video-assisted thoracic surgery has become the minimally invasive technique of choice for most thoracic and transthoracic surgeries. Spinal biopsy procedures, discectomy, decompressive corpectomy, interbody fusions, internal fixations, and debridement are now among the indications for thoracoscopic spine surgery. This review will focus on assessing the advantages and limitations of thoracoscopic spine surgery.

Conclusions Thoracoscopic spine surgery with a minimally invasive approach is a safe and successful alternative to traditional open thoracic spine surgery. It significantly reduces the morbidity associated with open thoracic procedures while maintaining the surgical procedure's safety and efficacy. The indications and applications of thoracoscopic spine surgery will continue to grow as surgeons gain more experience with the procedure and new endoscopic instruments are developed.

Background

Thoracoscopic spine surgery is a form of minimally invasive spine surgery (MISS) primarily used to treat thoracic spinal disk herniation and stenosis via endoscopic discectomy and decompression techniques, respectively. In contrast to the lengthy recovery time and related risks of an open approach, this minimally invasive technique primarily attempts to limit tissue trauma while maintaining therapeutic efficacy [1].

Thoracoscopies and video-assisted thoracoscopy surgery (VATS) were first developed in the early 1990s. Larger surgical instruments and improved access to foraminal pathologies were made possible because of Kambin's triangle. This triangle zone is formed by the exiting root anteriorly, the traversing root medially, and the superior end plate of the lower lumbar vertebra inferiorly [2].

With the development of high-quality video imaging, small endoscopes, and modified new instruments, video-assisted thoracic surgery has become the minimally invasive technique of choice for most thoracic and transthoracic surgeries. Spinal biopsy procedures, discectomy, decompressive corpectomy, interbody fusions, internal fixations, and debridement are now among the indications for thoracoscopic spine surgery. This review will focus on assessing the advantages and limitations of thoracoscopic spine surgery.

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Advantages

Endoscopic spine surgery reduces muscle trauma, tissue dissection, intraoperative blood loss, and epidural fibrosis and improves postoperative respiratory function as compared to traditional open spine surgery [3]. When compared to microscopic visualization, Ahn discovered that endoscopic visualization gives the neurosurgeon a larger visual field. [1] Ruetten et al. [4] recognized the visual field benefits of endoscopic techniques in thoracic disk herniation and stenosis, noting that a posterior approach may include inadequate visibility of the area anterior to the cord.

The use of endoscopic procedures in thoracic spine surgery has improved patient outcomes by shortening hospital stays, allowing for faster functional recovery, and improving overall quality of life [3]. According to Lin et al. [5] minimally invasive surgery would benefit the elderly, immunocompromised patients, and those with many comorbidities because it is can be performed under local or regional anesthesia.

Limitations

The technical hurdles that come with employing the endoscopic technique in thoracic spine surgery are an obvious constraint. The technique's mastery requires a long and difficult learning curve [1]. Bae et al. [6] discovered that endoscopic thoracic discectomy can be technically challenging in the surgical treatment of mid and upper thoracic disk herniations due to the complexities of vascular and neural structures.

In contrast to the anterior thoracoscopic approach which involves dissection around risky anatomic structures, one-lung ventilation, and nerve root retraction, the posterior thoracoscopic approach provided the surgeon with higher anatomic familiarity, manual dexterity, and little approach-related morbidity [6]. It should also be mentioned that increased technicality necessitates the use of not just a competent surgeon, but also an experienced surgical assistant and team [7]. When considering the drawbacks of adopting endoscopic methods in thoracic spine surgery, patient safety should be prioritized.

Indications

Initially, sympathectomy and thoracic discectomies were the most common procedures performed with thoracoscopic spine surgery. Following the development of anterolateral plating systems, spine surgeons began performing corpectomies in the thoracolumbar spine using thoracoscopic spine surgery. Many authors have used multilevel thoracic discectomy to correct spinal deformities. Metastatic tumors, spinal fractures, and adolescent scoliosis correction have all been treated by thoracoscopic corpectomy and stabilization [8, 9]. If the patient is concerned about the esthetics of the surgery, an endoscopic approach to thoracic spine surgery may be considered, as endoscopy improves cosmetic outcomes.

Endoscopic approaches, according to cadaver studies conducted by Abuzayed et al. [7], allow for better visualization of the anterior thoracic spine, which can improve treatment quality in conditions like herniated disks, vertebral body instability, infective lesions, and thoracic sympathectomy. The enhanced vision of the ventral thoracic spine has also been demonstrated to be beneficial in thoracic metastasis separation surgery, perhaps reducing the necessity for a costotransversectomy [10].

Contraindications

Endoscopic decompression procedures in the thoracic spine have been found to be ineffective in the treatment of calcified disks, very large disk herniations, severe stenosis, clinically significant instabilities, and severe fibrotic adhesions [1]. Except in patients with trauma-related tension pneumothorax or extensive hemothorax, in whom this operation may be therapeutic, severe respiratory failure may be an absolute contraindication. Extensive adhesions, past chest trauma, or surgery are all relative contraindications to thoracoscopic spine surgery. Hypoxemia, hypocoagulability, and cardiac abnormalities are only a few of the variables that can postpone but rarely prevent surgery. [8]

The requirement for single-lung ventilation is undoubtedly another drawback of thoracoscopic spine surgery. Patients with significant pulmonary dysfunction may not be able to sustain single-lung breathing for long periods of time. Open thoracotomy or an extracavitary exposure would be a better option for these patients. [8]

Thoracic anterior endoscopic approach

Mack et al. [11] published the first report on thoracoscope-assisted spine surgery in 1993. Despite the fact that open anterior approaches can be used to treat a variety of thoracic spinal pathologies [12, 13], large exposures are usually required, resulting in intercostal neuralgia, post-thoracotomy syndromes, and increased morbidity [14]. The thoracic anterior endoscopic approach could accomplish surgical goals such neural decompression and screw plate fixation while avoiding the higher risk of complications associated with open approaches.

Surgical technique

Regular spinal examinations and chest radiographs should be performed prior to surgery to check for pleural fluid, or adhesions in the pleural space [14]. To achieve single-lung ventilation for maximum surgical exposure, the patients are intubated with a double-lumen endotracheal tube. On a radiolucent table, the patient is placed in a lateral decubitus posture (Fig. 1). The sacrum, pubic bone, sternum, and scapula are all anchored to the operating table via a four-point support system. At this moment, the C-arm fluoroscope is set in place. A right-sided approach is preferred for access to the upper to middle thoracic spine (T3–10), whereas a left-sided approach is preferred for the thoracolumbar junction (T11–L2). [8]

Four portals are delineated around the level of the lesion (Fig. 2). The working portal is positioned directly above the lesion's level. In upper to middle thoracic spine instances, the endoscopic camera portal is placed caudal to the working portal. The suction/irrigation portal is placed ventral to the working portal, slightly cranial. The lung and diaphragm retractor portal is located ventral and slightly caudal to the working portal. [8]

A blunt dissection approach is used to open the first portal. The first trocar is implanted and the 30 endoscope is put into the thoracic cavity once the parietal pleura is opened and the lung is safely deflated. The remaining three trocar sites are placed under direct

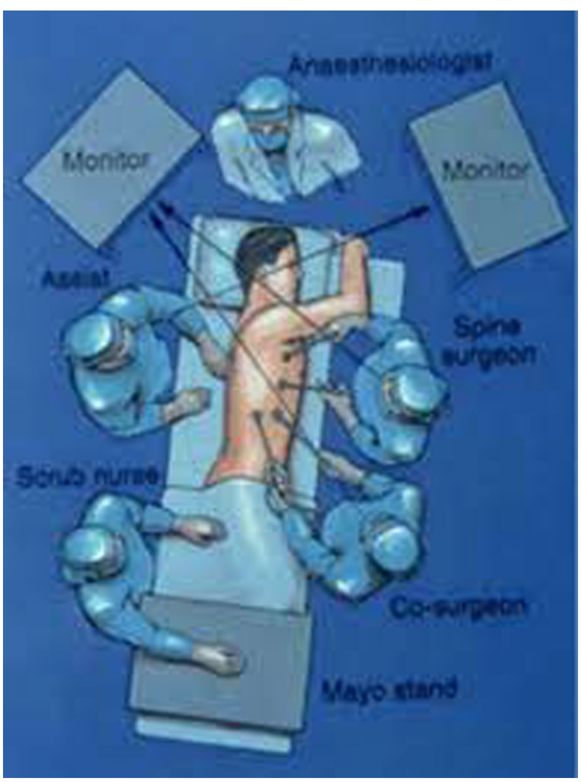

Fig. 1 Operating room Set-up for video-assisted thoracoscopic spine surgery [15]

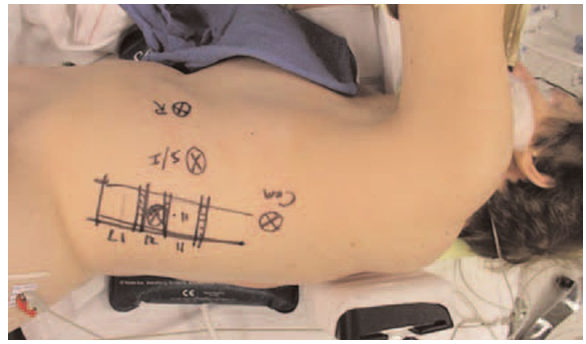

Fig. 2 After identification on lateral fluoroscopy, a photograph was taken of a patient in the left lateral position with the surgical anatomy marked on the skin. A circular X indicates the position of each of the four access channels. S/I = suction/irrigation portal; Cam = camera portal; R = retractor portal [8]

endoscopic vision. The anatomical structures that are most important are recognized (Fig. 3). [16]

After fluoroscopy identification, K-wires are inserted in the VBs that will receive instrumentation to maintain the orientation in a two-dimensional operating field (Fig. 4). The hooklike point of the harmonic scalpel is used to elevate and incise the parietal pleura. The segmental vessels are then located, ligated, and divided after the pleura is sharply dissected [8]. The disks are removed with rongeurs after being incised with an endoscopic knife. A median corpectomy is used to remove the intervening VBs. The ipsilateral pedicle must then be identified for spinal canal decompression (Fig. 5). In the upper

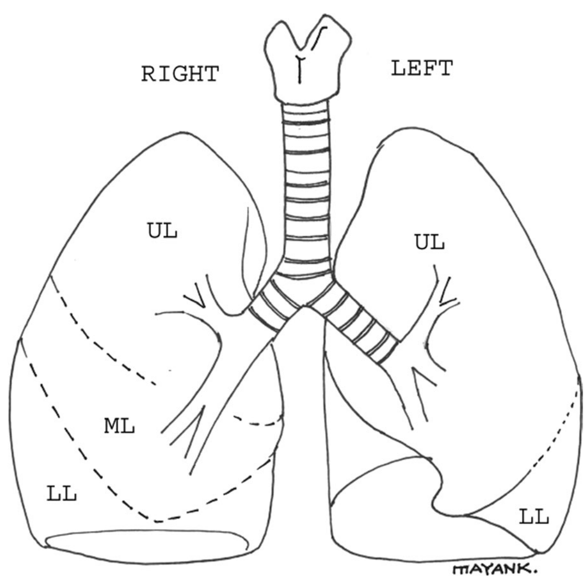

Fig. 3 Illustration of the trachea and lung lobes. Illustration by Mayank Mehrotra [17]

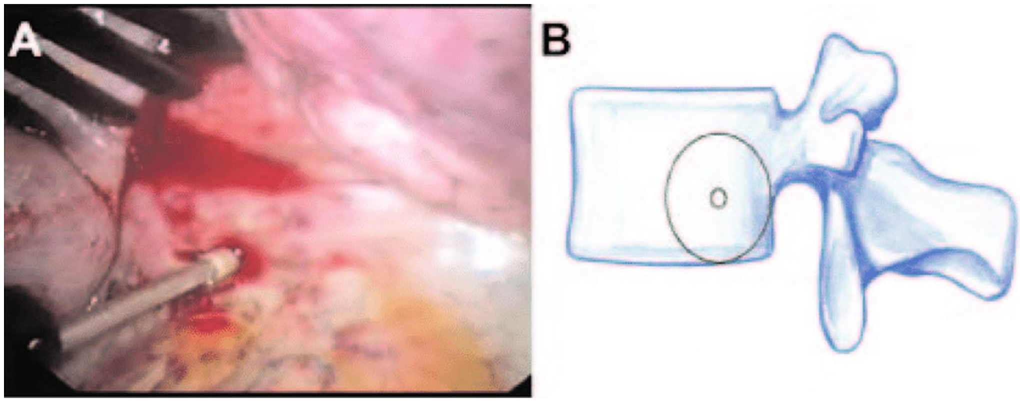

Fig. 4 **A** Intraoperative photograph of the K-wire being placed endoscopically with the C-arm. **B** The posterior screw's insertion point [8]

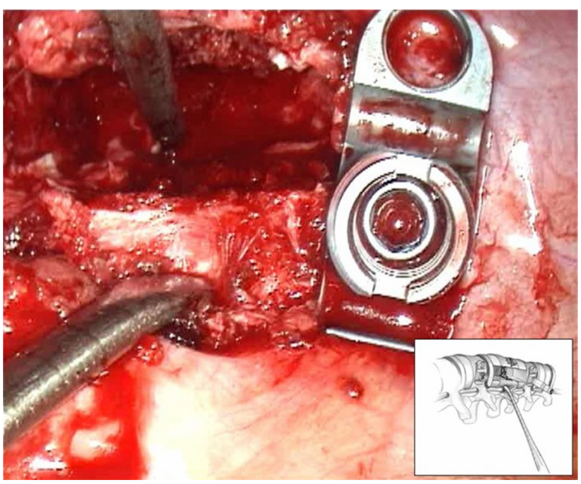

Fig. 5 Resection of the pedicle in order to expose the lateral dural sac [18]

and middle thoracic spine, the head of the rib must be removed.

Under lateral fluoroscopy, a short K-wire is inserted at the entry point, 10 mm anterior to the spinal canal in the upper or lower third of the VBs. The entry point is then decorticated by passing a cannulated awl over the K-wire. After the screw has been engaged, the K-wire is removed and the polyaxial screw–clamp assembly is installed (Fig. 6). The length of the plate is determined using the endoscopic expandable measurement equipment after both posterior screws have been put, and the plate is then fitted over the polyaxial screws. The anterior screws are then inserted using a specialized targeting device once the plate has been secured. After that, the screw plate assembly is locked. Additional anteroposterior fluoroscopic images confirm the screw and plate positions (Fig. 7). The thoracic cavity is then irrigated, and a tiny

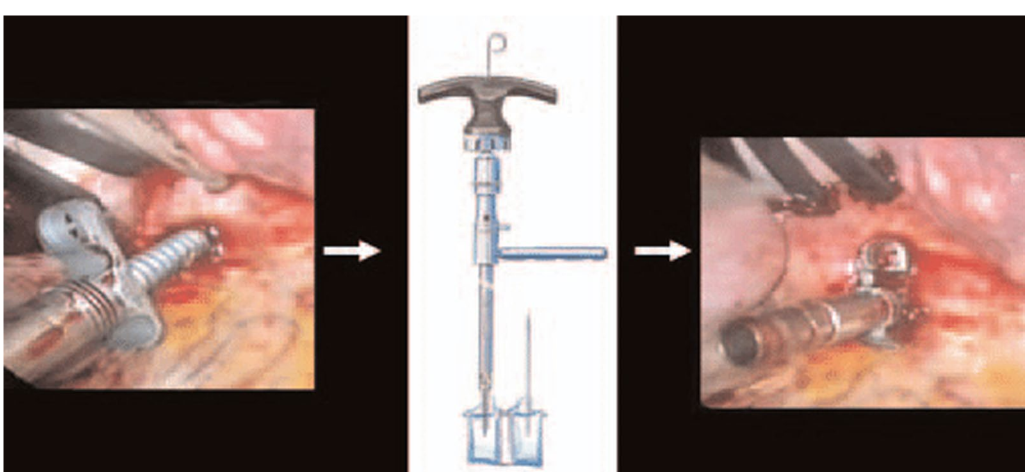

Fig. 6 The installation of a polyaxial screw over the K-wire and the removal of the K-wire are shown in intraoperative images and drawings [8]

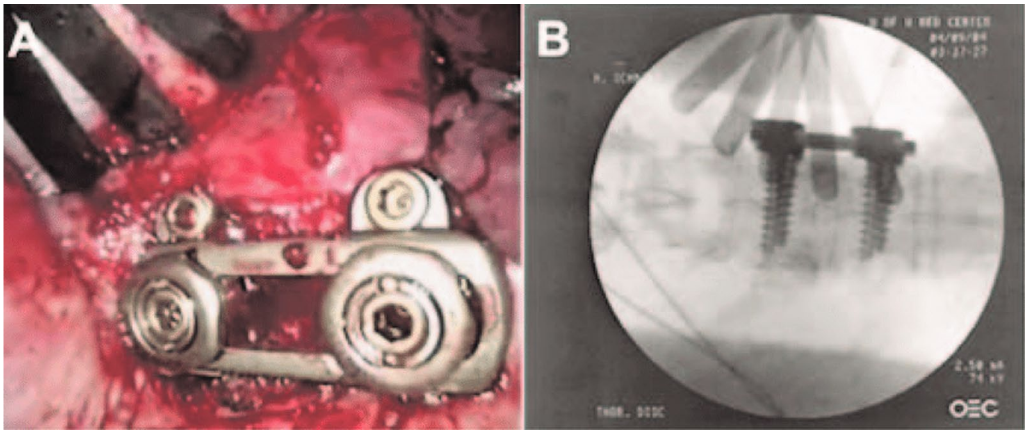

Fig. 7 **A** Intraoperative photograph of the final construct as seen through the endoscope. **B** Anteroposterior fluoroscopic image showing the screw plate construct in place after surgery [8]

Fig. 8 Clinical and cosmetic result of the procedure after suture removal [18]

No. 20 French chest tube is put through one of the portal sites at the completion of surgery. On the first postoperative day, the chest tube is usually withdrawn. The cosmetic result of the procedure is illustrated in (Fig. 8).

To achieve success with the anterior endoscopic techniques, the surgeon will need to learn new skills in tubology and scopology, which include keeping clean ports and scopes, maintaining scope stability, efficiently orienting the scope, navigating without tactile feedback, and adapting to monocular vision without depth perception. [19]

Thoracic posterior endoscopic approach

As a result of the minimally invasive nature of an endoscopic posterior approach to the thoracic spine, there is a lower chance of damage to posterior elements. An endoscopic procedure also necessitates a smaller laminotomy than an open approach [20].

Because of the small incisions, little muscle dissection, and even the possibility to do these procedures under local anesthetics, the transforaminal technique has the lowest morbidity [19]. The patient is placed in the prone posture for this procedure. Drawing a line from the lateral facet to the midpedicular annulus defines the endoscopic entrance point. Expanding reamers are used to extend the neural foramen after discography until endoscopic forceps can be successfully introduced to perform discectomy and decompression under endoscopic visualization [19].

In the case of disk herniation, the oblique paraspinal approach with tubular microendoscopy is frequently used for discectomy. The endoscopic entrance point is the superior border of the caudal transverse process, and the trajectory is less oblique than the transforaminal approach [19]. It is especially useful for discectomy of herniated disks that have become sequestered. Because of the rib curvature, tilting the endoscope laterally can be difficult, making access to the medial half of the disk space difficult. As a result, the lower thoracic spine may be the ideal candidate for this approach [21]. According to Osman and Marsolais [22], a more lateral, shallower posterolateral thoracoscopic approach provides greater access to the epidural area, but a more posterior or steep approach provides better access to lateral herniation.

Percutaneous endoscopic transpedicular thoracic discectomy was described by Jho as a posterolateral procedure. The herniated disks were removed laterally, and a cavity was created under the operating microscope. A 70° angled endoscope was then used to examine the ventral dura. One of the major drawbacks of this strategy was the reversal of the surgical field's perception [23, 24]. Choi et al. [25] added to the evidence of the safety and efficacy of percutaneous endoscopic thoracic discectomy performed from the posterolateral approach. They discovered that this strategy had positive results based on the visual analog scale and the Oswestry Disability Index.

In a case series, Nie and Liu [26] described endoscopic transforaminal thoracic foraminotomy and discectomy for the treatment of thoracic disk herniation. The majority of their patients were satisfied with the results, and all of their patients had quick pain relief. Wagner et al. compared a percutaneous transforaminal thoracic endoscopic foraminoplasty surgery to a thoracic microendoscopic discectomy. During transforaminal surgery, the needle should pass the isthmus but not the area beneath the superior pedicle. The inferior vertebral body's superior end plate is the target. [27]

Xiaobing et al. studied 14 patients who had thoracic spinal stenosis and were treated with percutaneous transforaminal endoscopic thoracic discectomy via the U route. They determined that this is a potential treatment option for thoracic spinal stenosis [28]. Telfeian et al. described transforaminal endoscopic surgery at the thoracolumbar junction. Technical challenges were the proximity of the kidney, rib, and the thecal sac/spinal canal diameter ratio. A safe path to avoid the kidney and rib was determined on preoperative axial MRI. The thecal sac/spinal canal diameter ratio was also given special consideration. The needle's path should enter the disk space at the midpedicle line [29]. Because traditional open procedures require longer incisions or more muscle dissection, the posterior endoscopic approach is suitable for soft, lateral disk herniation and patients who are more muscular. [30]

The full endoscopic interlaminar approach is a minimally invasive procedure to treat intracanal disk herniation not approachable by endoscopic transforaminal access.

Anesthesia for thoracoscopic spine surgery

General, regional, or local anesthesia can be used for thoracic endoscopic spinal surgery. The anterior approach is for general anesthesia only. Thoracoscopic spine surgery is performed after induction of general endotracheal anesthesia. Patients are intubated using a double-lumen endotracheal tube to achieve single-lung ventilation for maximal surgical exposure. Alternatively, a single-lumen tube and an endotracheal blocker can be used if double-lumen endotracheal intubation cannot be achieved. They deflate one lung by their way. [8]

In posterior approach (transforaminal approach) regional or local anesthesia can be used. Same-day surgery is possible with regional/local anesthesia because it provides for a shorter operative time from induction to extubation, a shorter period following wound closure and a shorter hospital stay. [31, 32]

Lack of patient consent and excessive intracranial pressure are absolute contraindications to regional anesthesia. Preexisting neurological disease, hypotension, hypovolemia, severe aortic or mitral stenosis, coagulation disorders, and left ventricular outflow blockage are all relative contraindications to regional anesthesia [33]. It is also worth noting that surgical bleeding in the dural puncture location acts as a natural blood patch, minimizing the risk of postdural puncture headache after regional anesthesia. [34]

In thoracic endoscopic procedures, a sedative such as midazolam IV (1–2 mg) and fentanyl IV (average starting dose: 0.5–2 μg/kg, taken in incremental boluses of 25–50 μg) is usually given first. Anesthesia is then achieved using 0.5% bupivacaine without epinephrine for 5–10 s, with the dose being adjusted based on patient characteristics such as BMI. [35]

Equipment and future insights

With the improvement of endoscopes in the 1990s and early 2000s, thoracic spine surgery was able to intervene in a variety of thoracic spine disorders [36]. Each type of thoracoscope has a 120-degree field of vision that may be spun circumferentially using the thoracoscope handle's turn dial [37]. Higher resolution for clearer images and novel accessory devices to lessen the surgeon's strain have all been added to the thoracoscope. The use of an image guidance system in conjunction with thoracoscopy (Fig. 9) allows for intraoperative CT reconstruction of the

Fig. 9 A navigation screen on the Medtronic StealthStation S8 that shows a trajectory view in two planes as well as axial and sagittal spine views. This view is being used by the surgeon to assess the best position for port placement and the best decompression trajectory. Please note the path from the rib head to the contralateral pedicle, which begins at the rib head and continues near to the spinal canal [40]

Fig. 10 Robotic ExcelsiusGPS surgical arm (**A**, Globus Medical Inc.) for placing guided pedicle screws, METRx tube (**B**, Medtronic Sofamor Danek) for minimally invasive tubular microdiscectomy, and lateral interbody arthrodesis (**C**). Globus Medical has granted permission to use Fig. 6A. Medtronic has granted permission to use Fig. 6B. Zimmer Biomet has granted permission to use Fig. 6C. [41]

patient's bony anatomy to guide drill guide placement, verify implant orientation, and assess bone resection and decompression [38]. Robotic-assisted MISS (Fig. 10) is the way of the future in thoracoscopic spine surgery, with an emphasis on improving both the accuracy and the trajectory of implant placement to assure efficacy and low complication risk [39]. The different equipments (implant and robotic- assistance) cannot be helpful in transforaminal approach. It is used in the anterior approach.

Outcomes of thoracoscopic spine surgery

Han et al. published the first large-scale report of patients undergoing thoracoscopic spine surgery in 2002. They reported a 98–100% success rate in 241 thoracoscopic surgeries, with a very low rate of morbidity, and no recorded deaths. When compared to open approaches, their results were promising [42].

Ringel et al. presented a retrospective evaluation of 115 thoracic (and lumbar) fixation surgeries in 104 patients. They used minimally invasive percutaneous techniques. This study similarly found high success rates, with postoperative CT imaging revealing that 87% of screw locations were good, 10% were acceptable, and 3% were unacceptable, necessitating a total of 11 revisions. There were no reports of new neurological impairments, surgery-related morbidity, or mortality among the patients [43].

MISS has been compared to traditional open surgical procedures in a few cohort studies. For the treatment of idiopathic structural scoliosis, Lonner et al. used a matched-pair analysis of 34 consecutive adolescent patients (in 17 pairs) who were randomized to either VATS or open posterior spinal fusion with thoracic pedicle screws. The VATS group had a significantly longer operating time than the posterior spinal fusion group, but less intraoperative blood loss [44]. In a retrospective cohort analysis of 40 patients, Lee et al. compared MISS to traditional anterior spinal surgery (TASS) for the treatment of thoracic (or lumbar) infectious spondylitis (23 in the MISS group, 17 in the TASS group). MISS patients had a lower mean estimated blood loss, less postoperative tube drainage, and a shorter hospital stay than TASS patients. The MISS group experienced a complication rate estimated to be one-third of the rate of complications in the TASS group, with no major complications in the MISS group compared with 4 major complications in the TASS group [45].

Ruetten et al. analyzed 55 endoscopic decompression surgeries for thoracic disk herniation or stenosis through interlaminar, transthoracic retropleural, or extraforaminal approach. At the 18-month follow-up, nearly all patients had sufficient decompression, with only one patient requiring revision because of secondary bleeding. Only one patient's preoperative myelopathy continued to worsen after surgery, but the symptoms of the other patients improved or disappeared. [4]

Complications of thoracoscopic surgery

Anesthesia, patient positioning, port placement, and instrument manipulation are all potential complications of anterior thoracoscopic spine surgery (Table 1) [46]. Single-lung ventilation is the most common cause of anesthesia-related complications. Incorrect installation, tubing size, and bronchial cuff over- or under-inflation might result in problems such as air leaks into the operated lung [46]. Other anesthesia-related risks include a vein injury during positive-pressure insufflation maintenance, which can result in CO2 embolism. Some patients may develop lung blebs that spontaneously burst and induce a pneumothorax. Because both lungs are perfused while one is ventilated, a ventilation-perfusion mismatch can arise, leading in arterial desaturation [46]. Non-ventilation of one lung for an extended period of time can cause an accumulation of excessive secretions in the airways, leading to atelectasis and pneumonia [46-48].

The brachial plexus may be affected by lateral decubitus positioning, either by pressure on the side the patient is laying on or by over-abducting the arm on the operated

Table 1 Complication rates of video-assisted thoracoscopic surgery reported in various studies

Complications	McAfee et al. [42]	Huang et al. [46]	Anand et al. [49]	Al-Sayyad et al. [50]
Intercostal neuralgia	6	4.4	2	0
Pneumothorax	0	2.2	5	1.4
Pulmonary embolus	0	0	0	1.4
Lung atelectasis	5	2.2	6	1.4
Blood loss ≥ 2000 ml	2	5.5	1	0
Chylothorax	0	1.1	0	0
Implant failure	0	1.1	0	0
Pneumonia	0	1.1	2	1.4
Conversion to open thoracotomy	1	0	1	0

N.B. The complications rates are expressed in %

side. If the peroneal nerve is squeezed above the fibular head, it might cause its palsy [46].

Injury to the lung parenchyma and other vessels may occur if the initial port is placed blindly, according to endoscope placement complications [46, 47, 51]. Lung adhesions may be the source of lung injury and postoperative air leakage during port insertion. Trocars that are not completely dislodged might develop subcutaneous or mediastinal emphysema [47].

Endoscopic devices and retractors can injure the lung parenchyma and major vessels in the thoracic cavity, resulting in postoperative air leaks and intraoperative blood loss [46-48, 52]. It's not uncommon for endoscopic devices to break inside the thorax when they're used too forcefully. The ability to retrieve quickly is aided by early recognition [46, 47]. When endoscope tips become excessively hot, they might cause burns. When unipolar cautery is employed inside a closed environment with an oxygen leak, there is a tiny risk of an explosion, especially in patients on high oxygen concentrations [44, 45, 51]. Intercostal neuralgia can develop after surgery as a result of pressure on the intercostal nerves caused by inflexible thoracoscopic ports or trocar placement [46, 47, 53].

Contamination from the camera head and light source might induce infection in thoracoscopic operations. Instrument placement and removal may result in excessive incisional wound damage, as well as an increased risk of skin contusion and infection [46, 53].

Some examples of common complications following posterior endoscopic thoracic surgery are durotomies, neural injury, wound infection, postoperative instability, and epidural fibrosis.

Methods to avoid complications

Patients with a history of lung disease should have lung function tests performed prior to surgery. Smoking cessation is advocated. Instead of a double-lumen tube, which may be too wide for a child's trachea, a bronchial blocker, Fogarty catheter balloon, or a single-lumen tube in the appropriate bronchus can be utilized in children [46].

End-tidal carbon dioxide monitoring is critical, and insufflation pressures should be kept below 10–15 mmHg to avoid mediastinal compression, cardiac tamponade, and probable circulatory collapse, especially in hypovolemic patients [46]. Postoperative respiratory therapy and intraoperative positive end-expiratory pressure on the ventilated lung with continuous positive airway pressure on the non-ventilated lung can help prevent atelectasis in both open and thoracoscopic surgery [46, 53, 54].

Palsies of the brachial plexus and common peroneal nerves can be avoided by providing adequate cushioning by placing rolls over pressure areas. Excessive flexion of the operating table should be avoided when opening the intercostal space in the case of severe spinal stenosis to avoid spinal cord injury [46].

Because the first thoracoscopic portal is created without thoracoscopic visualization, it might cause injury to the lung parenchyma and other vascular structures. In the case of lung adhesions, endoshears can be utilized to loosen adhesions and minimize lung damage during port insertion and postoperative leakage. Injury to the diaphragm and big intrathoracic vessels can be avoided by using proper techniques, such as entering the chest softly, avoiding the neurovascular bundle, placing all ports other than the original port under endoscopic monitoring, and viewing tools from entry to exit [46, 47, 52].

Because of the narrowness of the intercostal space, a rigid trocar greater than 12 mm should not be used [47]. The use of a flexible thoracoport (20 mm in diameter) is recommended because it not only protects incisional wounds during manipulation, but it also prevents incisional wounds from coming into contact with tumors or contaminated tissue [46, 47, 53, 55]. Monopolar cautery should be avoided when skeletonizing the head of the rib before removal to avoid electrocautery injury to the intercostal nerve.

The blood loss was shown to be reduced with thoracoscopic spine surgery. A minor incision (2 cm) is required to introduce the thoracoscope, while a bigger incision (5–6 cm) is required to execute complex spinal surgeries using the less invasive surgical technique. In addition, an intraoperative hypotensive anesthetic technique is usually employed [51]. Bleeding from port sites can be managed with the endoscope, bipolar coagulation, or metal clip ligation [46, 52, 56]. A Foley catheter can be inserted and the balloon inflated to tamponade the bleeding at the port site if the bleeding is severe. If the bleeding cannot be stopped, the surgery may need to be converted to an open procedure. In the event of severe bleeding, a thoracotomy tray should always be on hand [46, 47, 53, 56].

Segmental arteries should be divided close to their origins to provide collateral circulation through the internal mammary and intercostal arteries to reduce spinal cord infarction [55, 57]. T4 through T9 do not have as much collateral circulation as the cervical and thoracolumbar branches [55, 58]. Cord damage is rare when segmental arteries are divided unilaterally at their sources [55]. The more levels of ligation there are, the greater the chance of cord damage, and bilateral ligation is riskier than unilateral ligation [59].

Illustrative case

(Fig. 11)

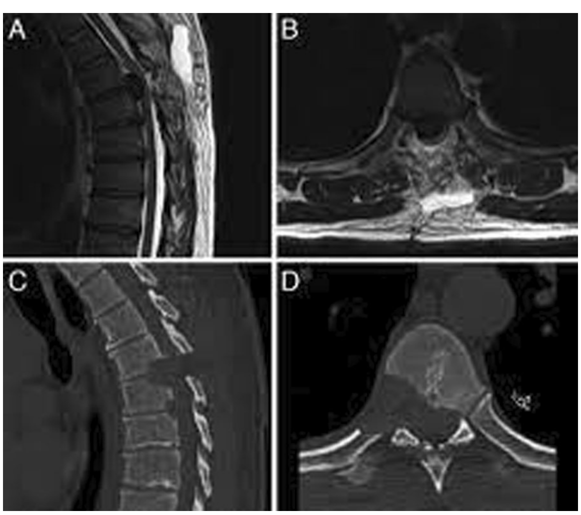

Fig. 11 Preoperative T2-weighted MRI of the thoracic spine, sagittal image (**A**) and axial view (**B**), exhibiting massive T5–6 central thoracic and smaller T6–7 disk herniations. The patient had previous T6 laminectomies. **C** and **D**: Postoperative thoracic spine CT, sagittal image (**C**) and axial view (**D**), showing bone decompression at T5–6 and T6–7.37, respectively. [40]

Conclusions

Thoracoscopic spine surgery with a minimally invasive approach is a safe and successful alternative to traditional open thoracic spine surgery. It can reduce operation time, blood loss, and hospitalization time. It significantly reduces the morbidity associated with open thoracic procedures while maintaining the surgical procedure's safety and efficacy. For endoscopic discectomy, decompression, corpectomy, and anterolateral fixation, this surgical approach has been proven to be an appropriate procedure. The indications and applications of thoracoscopic spine surgery will continue to grow as surgeons gain more experience with the procedure and new endoscopic instruments are developed.

Abbreviations

MISS	Minimally invasive spine surgery
VATS	Video-assisted thoracoscopy surgery
VB	Vertebral body
CT	Computed tomography
TASS	Traditional anterior spinal surgery

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Author contributions

The author MRN participated in the data collection and analysis, did the literature review, and wrote the manuscript. All authors have read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

All authors accept that only EJNS has all authority for publications and subsequent responsibilities.

Competing interests

The authors declare that they have no competing interests.

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