21 Thoracoscopic Fusion

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Introduction

The first thoracoscopic procedures were introduced by Jacobeus in the 1920s to perform intrapleural pneumolysis for the treatment of pulmonary tuberculosis [1, 2]. The evolution of modern thoracoscopic spinal procedures began in the 1990s after video-assisted endoscope systems were introduced [3]. Since then, operative and visualization instruments have constantly improved and helped to expand our surgical possibilities.

Anterior approaches to the thoracic spine have the advantage of direct access and visualization of anterior vertebral lesion. Vertebral body reconstruction is more feasible as the spinal cord can be avoided for the implantation of interbody construct. An anterior approach with stabilization may replace posterior surgery or may allow for the use of shorter segment fixation from the back.

Open transthoracic procedures are still more widely performed then thoracoscopic operations despite significant morbidity including intercostal neuralgia and postthoracotomy syndrome [4]. This is likely due to the technical challenges and the significant learning curve associated with thoracoscopic procedures. Several conditions such as extensive pleural adhesions or other intraoperative complications may require conversion to an open approach. Therefore, the surgeon must master both techniques.

As an alternative to pure open or pure thoracoscopic procedures, a tubular "mini-open" approach has recently been described for thoracic disc herniations and other pathologies [5] and will be described in detail in another chapter. Some authors have combined tubular and thoracoscopic access strategies to improve orientation and visualization during surgery in the thoracic cavity [6].

While the purely thoracoscopic approach is associated with a significant learning curve, we believe that it presents a truly minimally invasive option for achieving certain surgical goals, especially when it comes to the implant delivery and fusion.

Indications and Contraindications

The indications for thoracoscopic fusion procedures include:

- Anterior column fractures of the thoracic spine with and without spinal cord compression
- Posttraumatic deformity of healed fractures with or without instability
- Infections of the anterior column
- Primary or metastatic anterior column tumor
- Thoracic disc herniation
- Scoliosis correction

Contraindications to an anterior transthoracic approach include:

- Significant preoperative cardiopulmonary disease prohibiting single-lung ventilation
- Significant homeostatic disorder
- Extensive pleural adhesions
- Acute posttraumatic lung failure
- Previous chest surgery

Instruments and Implants

High-resolution rigid endoscopes are used with a wide diameter for a broad field of view. Endoscope tips should have a 0º angle if placed directly over the target lesion or a 30º angle if placed caudal or cranial to the target. The latter is generally preferred as it causes less interference with the working tools.

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Fig. 21.1 MACS-TL© plating system. The blue polyaxial screw is connected to a clamping element through which the yellow stabilization screw is inserted. A plate connects both clamping elements (Copyright Aesculap Implant Systems, LLC; used with permission)

Fig. 21.2 Vantage© system. Bolt at *top* of the figure, plate and locking nuts at the *bottom* (Images provided by Medtronic, Inc.; used with permission)

The thoracic cavity is accessed through flexible portals, which facilitate the insertion of the endoscope and operative tools. Flexible portals have the advantage of minimizing the pressure on intercostal nerves, thus lowering the incidence of intercostal neuralgia. A trocar can help to tunnel the portal through the chest wall [3]. Soft tissue dissection tools such as a pleural dissector, lung forceps, or a fan retractor are necessary to mobilize the lung for the transthoracic approach [3]. Instruments for spinal dissection are very similar to the ones used in open procedures with an adapted length to overcome the long working channel of 14–30 cm. They include rib dissectors, Kerrison rongeurs, disc rongeurs, curettes osteotomes, bone graft impactors, Penfield instruments, and microsurgical spinal cord and dural dissection tools. High-speed drills are used for bone dissection [22]. We prefer the diamond tip in the thoracic spine to reduce the chance of vascular injury.

Several implants have been designed specifically for thoracoscopic procedures. They require a low profile for anterolateral placement and need to be insertable through a small approach. Cannulated screws are advantageous as they can be guided by K-wires into the vertebral bodies [7].

In the lower thoracic spine and the thoracolumbar junction, double-screw plating systems are predominately used for single- or two-level fusions after corpectomy or discectomy. Most are angle-stable, four-point fixation devices with two screws inserted into each vertebral body (Fig. 21.1). As the anteroposterior diameter of the vertebral bodies narrows caudocranially, two-screw fixation systems become less appropriate for cranial segments. Single-bolt plating systems [8] (Fig. 21.2) are thus more applicable for fusion procedures in middle or upper thoracic segments.

Biomechanical studies showed that plate/bolt constructs are stiffer, in terms of flexion and axial rotation, than plate/screw or dual-rod constructs after two-level corpectomies [9]. In addition, single-bolt systems make two-level fusions more technically feasible when compared with double-screw constructs. The range of possible screw trajectories is limited by the relative positions of the insertion site on the vertebra and the portal on the skin. Thus, placing a single large bolt into the vertebral body is easier than placing two smaller screws at separate angles [9].

Several cages for anterior column reconstruction are available. Expandable titanium cages are feasible for thoracoscopic procedures as they can be inserted when collapsed to fit through a small skin opening. The possibility of expanding and collapsing the cage in situ makes optimal placement easier and eases kyphosis correction in fractures compared to non-expandable cages [10, 11].

For bone autograft, tricortical iliac crest is still widely used for reconstruction purposes despite donor site morbidity. In terms of fusion rates, subsidence, or implant failure, no consensus exists regarding the superiority of cages compared to bone autograft or allograft [12–14].

Anesthesia

All procedures are performed under general anesthesia. Patients have to be intubated with a double-lumen endotracheal tube in order to perform single-lung ventilation [11].

After blocking the airway on the approach side, the lung becomes atelectatic, which facilitates intraoperative mobilization and retraction.

Patient Positioning

The patient is placed in a lateral decubitus position with the hips taped to the operating table. In addition, there is four-point support at the scapula, symphysis, and sacrum. Securing the patient facilitates intraoperative tilting of the operating table, which increases surgical exposure by gravity, thus reducing the need to retract soft tissue mechanically [19].

A left-sided approach is generally recommended to avoid the liver as well as the inferior vena cava. The disadvantage of a left-sided approach is that it often requires further mobilization of the aorta depending on the procedure. Other factors related to the patient-specific anatomy or pathology may override these concerns; for example, if a calcified thoracic disc herniation presents towards one specific side, an ipsilateral may be safer and more efficient. Approaches to the upper thoracic spine (T1–T5) require abduction of the upper arm in order to place portals in the corresponding intercostal spaces [19].

After the patient is positioned, the operative level should be identified and marked using fluoroscopy. Correct identification of the lesion and projection of the disc interspace or vertebral body of interest onto the skin using skin markers is of the greatest importance and requires intraoperative fluoroscopy. We use a preoperative CT that should include the lower portion of the cervical spine and/or the first two lumbar levels in addition to the pathology. We then count either from the first rib down or from the lowest rib cranially.

Portal Positioning

Most thoracoscopic fusion procedures require three to four portals, each serving an individual function. Spinal dissection tools, drills, and instrumentation devices are inserted through the working portal (12.5 mm) and the endoscope through a viewing portal (10 mm). Additionally there is a suction/irrigation (5 mm) and retractor portal (10 mm) [10, 11, 15, 16].

Positioning of the portals is a critical operative step as it determines the trajectory of working tools and implantation devices. The most commonly used configuration places the working portal directly over the lesion with the endoscope positioned on the same axis two to three intercostal spaces away cranially (lower thoracic spine) or caudally (middle or upper thoracic spine). Suction/irrigation and retractor portals are positioned ventral to the working portal. This setup prevents interference of the endoscope with dissection tools and allows direct vision of the target. The disadvantage of this configuration lies in the fact that the working portal is not directly aligned coaxially to the trajectory of the fixation screws. Because of this perceived inadequacy, Dickmann described a configuration which places four portals over the intended screw trajectories [18].

As a general principle, to prevent brachial plexus and vessel injuries (Fig. 21.3), the portals should not be inserted through the axillary space in the upper thoracic spine (T1–T5). The first and second intercostal spaces should be spared as well to avoid the subclavian vessels.

In the lower thoracic spine (T9–L1), diaphragm incision may be necessary for spine exposure. Fusion procedures on T12–T1 require portal insertion in the retroperitoneal space [18].

The endoscopic portal is to be inserted first. An approximately 1.5 cm skin incision is placed parallel to the intended intercostal space. Blunt dissection follows through the intercostal muscles and the parietal pleura into the thoracic cavity. After the endoscopic portal is inserted, the remaining portals follow under endoscopic visualization.

Spinal Exposure

Mobilization and cautious retraction of the lung exposes the parietal pleura covering the vertebral bodies.

After verifying the correct level by fluoroscopy and internal rib count, the parietal pleura has to be incised. The primary incision should be placed over the rib heads in order to avoid the segmental vessels, which run along the midportion of the vertebral body. Thereafter, the pleura must be carefully mobilized over all vertebral bodies intended to be fused, as well as over the corresponding rib heads (Fig. 21.4). This follows ligation and transection of the segmental vessels. In cases when extended mobilization of the aorta is necessary, additional segmental vessels from adjacent segments have to be ligated and divided.

In order to expose the pedicle and the lateral surface of the vertebral body, the rib heads along with up to 2 cm of the proximal rib need to be resected. This is accomplished by disarticulating the costovertebral joint and transecting the rib with either a drill or an oscillating saw. Prior to resection, the neurovascular bundle has to be detached from the caudal rib margin.

The spinal canal is accessed by resection of the pedicle with a Kerrison rongeur from caudal to cranial. The pedicle can be thinned out with the drill first. This allows for visualization of the dura and the posterior edge of the vertebral body, which is crucial for avoiding spinal cord injury in endoscopic decompression and fusion procedures [20].

In order to approach the thoracolumbar junction, the diaphragm, which inserts at the first lumbar vertebra, has to be incised. The incision should be placed parallel to the

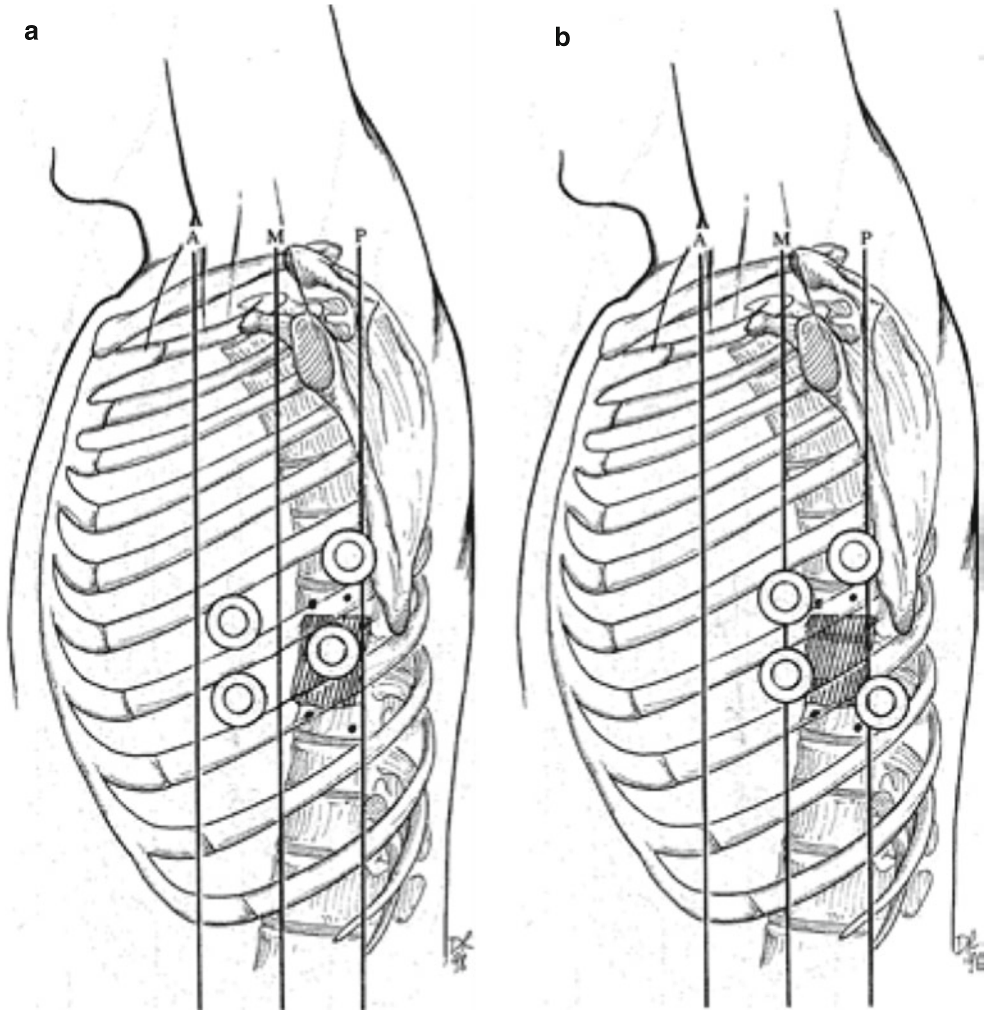

Fig. 21.3 (**a**) Displays the most widely used portal configuration with the working portal placed over the target area (hatched vertebra). The endoscope portal is placed proximally, the suction and irrigation portals ventrally (in between the anterior and medial axillary line) to the working portal. (**b**) Displays a portal configuration described by Dickman [18] with all portals aligned along the intended trajectory of the screws (*black dots* on vertebrae)

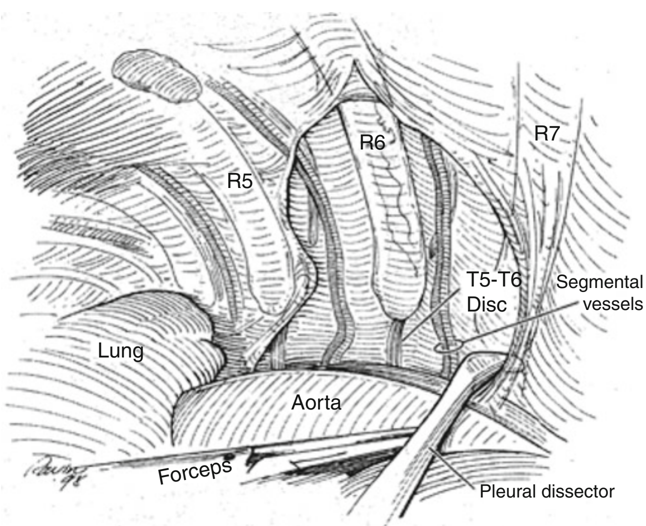

Fig. 21.4 Spinal exposure of the 6th and 7th thoracic segment. The parietal pleura is mobilized over both involved ribs. The segmental vessels have to be prepared

diaphragm attachment to spare muscle fibers, which prevents postoperative herniation. In the retroperitoneal space, the insertion of the psoas muscle has to be prepared and mobilized posteriorly to expose the lateral surface of the vertebral body.

Fusion Techniques

Discectomy and Fusion

To perform a discectomy the patient is placed in the aforementioned decubitus position, with the working portal inserted over the target segment. Thoracic discectomies down to T8 usually do not require instrumentation unless a large portion of the vertebral body is resected. Based on anecdotal evidence, below T8 we prefer to perform an interbody fusion with instrumentation. The thecal sac and the disc herniation are approached as described above. Prior to disc extraction the posterior polyaxial screws attached to the clamping element are implanted into the cranial and caudal vertebral body of the involved segment. They serve as a landmark throughout the procedure and facilitate distraction of the segment during discectomy or implantation of an interbody construct. After the vertebral body and the spinal canal have been exposed, K-wires connected to an impactor are placed on both vertebral bodies approximately 10 mm ventral to the posterior edge and 10 mm from the distal end plate [16]. K-wires are then advanced into the vertebral body under fluoroscopic control. Strict parallel alignment to the posterior border of the vertebral body is mandatory to avoid perforation of the spinal canal. After decortication with a cannulated punch, the posterior polyaxial screw-clamp assembly is inserted, guided by K-wires under fluoroscopic control. The screws have to be aligned parallel to the end plate and the posterior border of the vertebral body. K-wires are removed after the screw has been engaged [16].

In the next step, the intervertebral disc is incised and disc material extracted with disc rongeurs. In many cases a partial corpectomy above and below the disc space may be necessary to avoid manipulation of the spinal cord during removal of disc fragments.

The proximal rib harvested during the approach is used as an interbody construct. The autograft has to be tailored to fit into the disc space, and a recess to anchor the cage needs to be drilled into both vertebral bodies to prevent migration [21]. Prior to implantation the segment can be slightly distracted to ease implantation and to facilitate graft compression.

After the distance has been measured between both screw heads, a matched size stabilization plate is inserted and fixed to the polyaxial heads with fixation nuts. Now the anterior stabilization screw is attached to the clamp and screwed into the vertebral body. The anterior screw should be 5 mm shorter than the posterior screw to prevent contact. Finally, the polyaxial mechanism is locked with locking screws, which are tightened with a torque wrench.

After dissection and instrumentation is completed, the operative field is irrigated with antibiotic solution and inspected. Loose bone or disc fragments have to be removed. Epidural hemostasis should be carried out with bipolar cauterization or topical hemostatic agents. Portals are removed and the incision sites are inspected for bleeding. In the next step, chest tubes are inserted through the portal incisions under endoscopic vision and secured to the chest with purse-string sutures. An apical chest tube is used to expand the lung by creating a pressure gradient. Inferior and posterior chest tubes are used to drain fluid from the thoracic cavity. Finally, the endoscope is removed, and the remaining portal incisions are closed with subcutaneous sutures [21].

Corpectomy and Fusion

As described above the patient is positioned in a true lateral decubitus position. The working portal is placed over the target vertebral body. If double-screw systems are used, placement of working portals aligned to the screw trajectory can also be considered.

This section will describe the application of a lateral plate for instrumentation along with an expandable cage for reconstruction.

Spinal exposure is performed as described above. At the corpectomy level, the rib head along with the proximal rib and the pedicle have to be resected. Rib bone is saved as grafting material; resection of the pedicle enables visualization of the spinal canal and lateral dura.

After removal of the proximal and distal IVD with disc rongeurs and preparation of the end plates, a large cavity is drilled into the center of the vertebral body. Subtotal resection follows, preserving the anterior and contralateral walls. The posterior cortex and posterior ligament are then resected into the cavity, which now enables removal of an epidural mass [22]. Alternatively, osteotomes can be used to start the corpectomy bone removal.

Prior to instrumentation, a rectangular graft bed has to be prepared by thoroughly removing all disc material and cartilaginous end plates. The bone surfaces must be flush and parallel to the surface of the cage.

Under fluoroscopic control, a K-wire is inserted in the intended bolt entry point of the proximal and distal vertebra. The ideal bolt position is the center of the lateral surface on the vertebral body, aligned parallel to the end plates and the anterior wall of the spinal canal. After decorticating the entry point with a cannulated punch, bolts are inserted over the K-wires and screwed into the vertebral bodies under fluoroscopic control until bicortical fixation is achieved. Length of the bolts should be calculated preoperatively on CT or MRI.

In the next step, the expandable cage has to be implanted. The height of the corpectomy site is measured using a parallel distractor. A scale on the handle of the distractor indicates the height of the implant in its neutral position. In addition, the proper cage end plate size and angulation, which depend on the level of implantation, have to be chosen.

The bone cups of the selected cage are now filled with bone graft. Thereafter, the cage is grasped with an implant holder, inserted into the defect, and positioned in the center of the vertebral end plate. The parallel distractor is now used to expand the cage until sufficient compression is achieved to prevent migration. If present, kyphotic deformity can be corrected by cage expansion under fluoroscopic control. The implant can always be collapsed to its neutral height for repositioning and explantation. In order to enhance the fusion process, bone graft is packed in and around the cage.

In the next step, a matched sized plate is inserted over the bolts; the curve of the plate should match the natural thoracic kyphotic curvature. The nuts are inserted with the smooth surface positioned against the plate. Finally, a limiting torque wrench driver is used for tightening.

Hemostasis, portal removal, chest tube insertion, and wound closure should be carried out as described in the discectomy section.

Complications

In general, the complication rate of thoracoscopic procedures is relatively low. Yet every step of the operation has potential risks.

Intraoperative pulmonary or anesthesia-related complication can derive from incorrect tube placement, potentially leading to insufficient gas transport. Single-lung ventilation generally induces a ventilation-perfusion mismatch, which can lead to arterial desaturation as well as to inefficient CO_2 clearance with subsequent acidemia. For this reason, detailed preoperative pulmonary examination is mandatory to rule out high-risk patients. Correct positioning of the tracheal tube has to be verified bronchoscopically [17]. Continuous blood gas analysis needs to be obtained to monitor oxidation and pH status during the procedure.

Pneumothorax and atelectasis are the most common postoperative pulmonary-related complications. Persistent pneumothorax can be due to an air leak caused by a lung defect. Continuous suction through chest tubes should be applied primarily for treatment. If ineffective, reoperation may be necessary to staple the lung defect. Atelectasis is caused by nonventilation of the ipsilateral lung with subsequent accumulation of secretions in the airway. Periodic intraoperative lung reinflation and postoperative intermittent positive air pressure ventilation minimize the risk [17].

Intraoperative vascular complications require immediate response as severe bleeding can quickly impair endoscopic visualization, making it difficult to maintain orientation in the surgical field. Bleeding of segmental vessels often occurs due to inadequate exposure during the approach and should be treated with coagulation or clipping.

Injuries of large intrathoracic vessels like the aorta, venae cavae, or azygos vein are potentially life-threatening complications and require conversion to an open approach to facilitate repair [16]. By confining the operative field using visual landmarks, laceration of the aforementioned vessels can be prevented. Preoperative endovascular embolization should be attempted in order to minimize bleeding during resection of highly vascularized tumors.

Insertion of instruments should always be carried out under visual control. Instruments are to be maneuvered strictly with two hands and should be additionally stabilized against the chest wall to avoid uncontrolled movements [16].

Puncturing of the dura leads to CSF leaks. Although technically challenging, it is recommended to suture the defect to be watertight even if this necessitates conversion to an open procedure. The negative intrathoracic pressure promotes persistent CSF leak. Lumbar drainage should be applied postoperatively and the patient kept flat for 72 h; the chest tubes should not be placed on suction, if possible.

Postoperative Care

Unless preoperative pulmonary conditions like COPD or cardiovascular diseases are present, the patient is extubated immediately after the procedure. Chest X-rays are recommended on the operative and first postoperative day. Further follow-ups depend on the occurrence of pulmonary complication and the ventilation capacity of the patient.

Under normal conditions without signs of after bleeding, the chest tubes are removed on the first postoperative day to facilitate early mobilization and ventilation training. Anteroposterior and lateral X-rays targeting the operative field are obtained on the second postoperative day to rule out operative complications such as implant failure or dislocation as well as signs of instability. We further perform follow-up X-rays and CT scans after 6 months and 1 year to evaluate the fusion process of the involved segments.

Conclusion

Thoracoscopic fusion procedures represent a minimally invasive alternative to open thoracotomy approaches. Constant advancement of implantation devices as well as endoscopic instruments helps to facilitate these challenging operations. The patients benefit from reduced tissue trauma, diminished blood loss, and lessened postoperative pain. However, the procedure has a steep learning curve, is technically demanding, and often requires longer operation time when compared to open procedures.

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