Therapy

5

5.1 Basic surgical techniques with special considerations on skin incisions

Anton H. Schwabegger

While in earlier decades skin horizontal incisions extending up to 30 cm with resulting unsightly scars were not uncommon for surgical access across the anterior thoracic wall and décolleté (Figs. 1 and 2), nowadays incisions and therewith resulting scars of 3–10 cm usually suffice for the different techniques of correction applied.

Fig. 1. Large horizontal scars crossing the midline, funnel chest surgery performed four decades ago

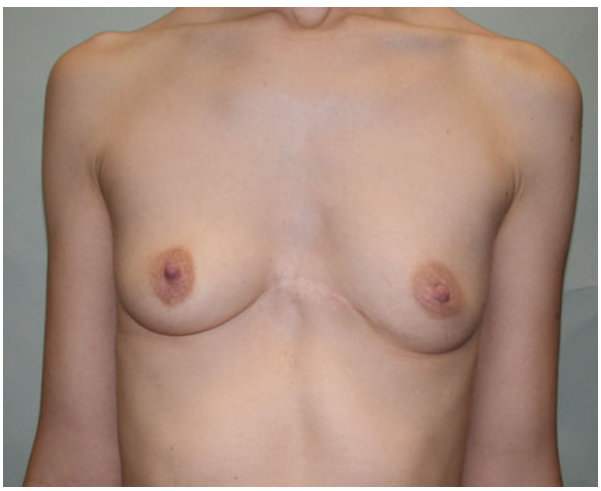

Fig. 2. Well-hidden scar at the inframammary crease, also resulting from funnel chest surgery decades ago, but with still very well visible stain within the décolleté

The conventional surgical accesses in male patients with keel or in funnel chest deformity usually are set centrally above the sternum. Although no evidenced data are available so far, which kind of incision, whether vertically, horizontally or with other distinct design like lazy-S or W-shaped (Figs. 3–6) will lead to development of the slightest and unrecognizable scar (Chapter 12.2). Particularly the presternal region is well known and accused to development hypertrophic scars or even cumbersome keloids [4], even if one follows the criteria of skin incision along the relaxed skin tension lines (RSTL). However, within our own series of patients operated on keel chest deformity, we have observed

Fig. 3. Horizontal inconspicuous scars placed along the RSTL in a 27-year-old man who received a horizontally placed custom-made silicon implant into lower arch rib depressions, via the left incision even a minor gibbus of the fourth and fifth left rib cartilages parasternally could be resected simultaneously

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Fig. 4. W-shaped central access for sternum elevation during the MIRPE-procedure, scar fortunately remained soft 4 years after the initial surgery. However, nowadays a scar within the submammary crease would be preferred

Fig. 5. Horizontal scar at the right side, this small incision, enabled multiple cartilage resections of the second to the sixth rib in an asymmetrical keel chest deformity without sternum malrotation

only a few partial hypertrophic scars but no keloids. Above all, in the correction of keel chest deformities, the continuous postoperative compression of the scar by the keel chest brace (Chapter 7.4) over a period of 6–8 weeks may distinctly be responsible to work against such disadvantageous development of hypertrophic scars (Fig. 7) or keloids [6, 8]. On the other hand, relative skin excess is generated through the skeletal reduction of the cavity in the funnel or the convexity in the keel

Fig. 6. Arched incision for access to microvascular sternum turn-over flap (Chapter 6.6.5) in extensive pectus excavatum

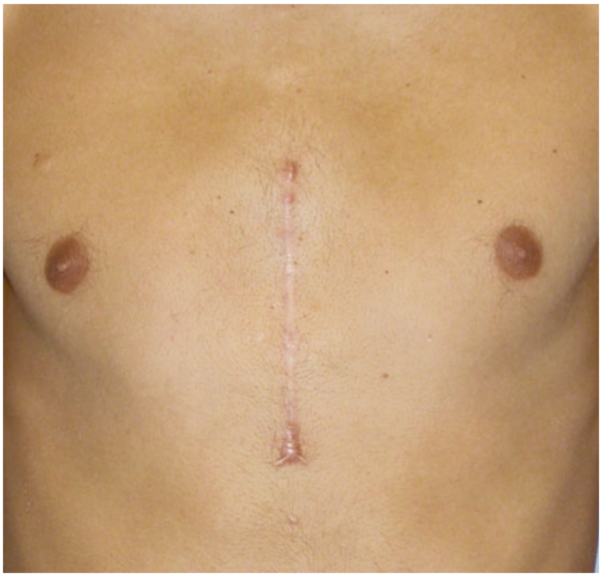

Fig. 7. Vertically placed scar after extensive keel chest correction including horizontal sternum osteotomy. Notice the flat and smooth part of the scar, exactly where the silicon pad of the keel chest brace (Chapter 7.4) was placed for 8 weeks. The scar extending the area of the pad cranially and caudally, thus left without compression developed hypertrophic zones

chest deformity, which relaxes the wound seaming from any tension. Therefore the causing agents namely wound tension, which is responsible for the excessive collagen production are omitted and therewith any hypertrophic scar development is circumvented too, hypothetically. However, it is very well known clinically but still without high-level evidence data, that compression therapy on hypertrophic scars and keloids

Fig. 8. This patient had extensively deep pectus excavatum operated at the age of 15, using a modified approach with bilateral submammary incisions remodeling of sternum and adjacent ribs, additionally implantation of a pectus bar. Situation 1 year after pectus-bar explantation at the age of 17 and moderately grown breasts shows slight displacement of the scars to their undersurface, however well concealable by bra

Fig. 9. Definition of the submammary crease laterally during MIRPE surgery to place the incisions exactly there. Preferably these incisions should already be marked in standing position prior to surgery, to include the gravitational effect on the tissue, thus presenting with a different location of the lateral and submammary crease

Fig. 10. Lateral aspect of a 17-year-old female with inconspicuous scars for the MIRPE-procedure exactly placed into the lateral breast fold

definitely benefits their outcome and aesthetic appearance [2, 6].

In female patients the skin incisions are placed into the submammary crease, similar to the surgical access in reduction mammoplasty (Fig. 8), therefore they are very well hidden in a frontal aspect. The lateral incisions in the MIRPE-technique are also placed into or along the extensions of the submammary crease, where they ideally can be concealed by bra (Figs. 9 and 10).

In the correction of the pectus carinatum or pectus excavatum deformity, scars in the median line must be avoided, i.e., the female décolleté should remain untouched by incisions in any case. This may impede the access to the presternal region, especially when a horizontal osteotomy of the sternum is necessary. However with the experiences in reduction or augmentation mammoplasty, this problem can be handled thoroughly well. A specially angled blade and oscillating saw applicable especially for that submammary access to reach the sternum (Fig. 11) is described in Chapter 9.

For the case that simultaneously to a chest remodeling access in female adults also mammary implants were necessary, the correct planning of scar positioning may become cumbersome. Herewith it has to be considered

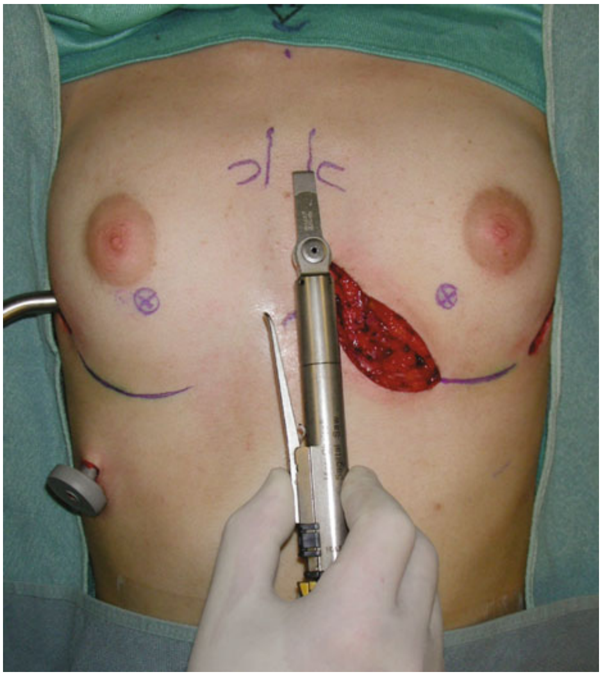

Fig. 11. Submammary access for horizontal sternum osteotomy in patients with either keel or in this particular case funnel chest deformity, enabling subcutaneous approach of the oscillating saw with an angle blade to the desired level of the osteotomy

Fig. 12. Surplus of tissue without excision of excessive skin after correction of pectus arcuatum causes skin folding

Fig. 13. Retracted scar in this slightly obese patient, potentially caused by inappropriate suture technique with subcutaneous fat necrosis and ensuing tissue loss with scar formation subcutaneously

that through the implant expansion of the mammary gland tissue also skin distension will occur, leading to a dislocation of the scar from the inframammary crease further cranially and therewith scars come to lie at the underside of the breast skin (Fig. 8). Therefore comprehensive experiences with the augmentation mammoplasty procedures are required in this simultaneous correction to optimize the aesthetic outcome, which is of major importance in the female patient particularly. Disfigured and prominent, usually only aesthetically disturbing rib arches, as far as they not can be corrected by any central access, or are subject of solely isolated treatment, are resected through separate incisions, exactly following the lines of Langer or RSTL [1, 3, 5, 7]. The wounds of all incisions are closed by means of intracutaneous running sutures only. Because usually a relative surplus (Fig. 12) of skin emerges by reduction of a cavity or a convexity, absorbable subcutaneous sutures for the relief of skin tension are unnecessary, because they are subject to produce localized necrosis of subcutaneous fat with ensuing development of scar contraction in the subcutaneous fatty tissue. Such adherent and sunken scars (Fig. 13) then generate so-called unaesthetical “eye-catchers” and persistently direct the attention often more on itself than on the previously existed deformity.

The aesthetically sensitive zone of the female décolleté should, if possible,remain surgically untouched in any case and therewith taboo for any scarring. Nearly all surgical accesses to the sternum, to the parasternal rib region even highly up until to the second or third rib are manageable out from an access along the submammary crease. On the one hand, connecting scars horizontally between both breasts tend to develop scar contraction and breast distortion. On the other hand, and in contrast to scars along the submammary crease, such horizontal scars crossing the midline are well visible (Figs. 1 and 2) lifelong for others and for the patient when looking downward or into the mirror. Thus the stigma of deformity would only have been replaced through the stigma of a well visible scar then, which would mean no definite improvement of body image and self worth.

With the implantation of custom-made silicone implants, the scars at the chest should preferably come to lie distant from the median line, again to circumvent the zone of probable scar hypertrophy or keloid formation, and furthermore to avoid (Figs. 10 and 11 in Chapter 6.5) stigmatization of the central body aspect for aesthetic reasons above all. In female patients the endoscopic implantation of custom-made silicon blocks, which are brought in through a periumbilical incision [4], represents an interesting alternative to avoid scars in the breast area. For sure, the endoscopic preparation of the recipient pocket via the distant access is a more skillful and time-consuming procedure than a direct access, but the aesthetic benefit especially for young and female patients may be impressive.

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5.2 Positioning of patients during surgery

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In almost all operations for the correction of thoracic wall deformities, the patient is positioned supine on a flat operation table, and he/she will retain this position during the entire time of the intervention. A particular exception is the correction of an asymmetric female breast as far as this concomitant deformity is corrected simultaneously in the same operation with the thoracoplasty. Herewith the torso of the patient usually will be erected up to 45° to estimate the natural form and ptosis of the untouched contralateral breast, so that the breast to be operated can be adapted optimally to that relevant shape. An other exception from pure supine positioning is necessary in harvesting of a latissimus dorsi flap for the correction of a Poland-syndrome exemplarily, pedicled or transplanted as a micro (neuro)vascular flap (Chapters 10.1 and 10.3). In such cases the position of the torso must either be solely elevated [2] or entirely turned to a lateral decubitus position to enable dissection of the latissimus dorsi flap as a partial or entire flap to be transposed or transplanted. A further exception is the surgery for pectus bar explantation in children because herewith and in contrast to the more laterally extended shape and overall rigidity of the thorax in adults, the pectus-bar needs not to be bent back to a straight shape, but rather can be extracted from the thorax along the almost uniformly round-curved shape of the implanted pectus-bar, with the child positioned laterally [1] (Chapter 6.9).

5.2.1 Positioning during funnel chest surgery

In the correction of the funnel chest deformity, utilizing either the MIRPE, similar endoscopically assisted semi-open or other techniques, the arms are adducted (Fig. 1) at the shoulder and bent in the elbow joints to cranial around 90° to gain sufficient space for the manoeuvres of the endoscopy equipment (Chapter 5.4 with Figs. 1 and 2 and Chapter 6.3 with Figs. 5 and 8). In addition also the placement of a pillow underneath the thoracal spinal column is recommended to elevate the thorax to some extent and therefore to expand the overall maneuverability of the thoracoscope (Figs. 1 and 2). Particular care must be taken to a correct positioning of the arms, as

Fig. 1. Patient positioned for the MIRPE technique, both arms are abducted and bent in the elbow joint in order to gain sufficient space for maneuvers for the endoscope, the tunnelizer and the pectus-bar implantation tools

Fig. 2. Intraoperative situs with arms adducted and bent at the elbow joint in an adult tall male, undergoing pectus excavatum deformity correction by a combined approach

brachial plexus lesions, temporarily or even permanently may result from over-elevation or unintended retroversion potentially lasting for hours in the cases requiring complex remodelling.
For the particular cases that surgery is performed according to the conventional technique of Ravitch exemplarily and no additional lateral approach to the thorax is mandatory, both arms will be adducted to the torso for the purpose of relaxation of the pectoralis muscles. Even the origins of the rectus abdominis muscles are advantageously relaxed by that setting, due to slackening of the entire thoracic cage, consecutively to relaxation of the Pectoralis major muscles.

Fig. 3. Patient positioned for keel chest correction, surgery is already completed. Both arms remained adducted in order to relax the pectoralis major and rectus abdominis muscles for either transmuscular or submuscular access

5.2.2 Positioning during keel chest surgery

In contrast to the positioning in the (minimally) invasive funnel chest surgery in the correction of the keel chest deformity both arms should be adducted to the torso in order to relax the Pectoralis major muscles (Fig. 3). By that means the muscle preparation is facilitated, independently if either the muscles are conventionally elevated as flaps from the skeletal thorax, or a muscle split technique is applied to approach the rib cartilages [3]. Moreover, through this positioning, i.e., the adduction of both arms, the lateral tension of muscles of the shoulder girdle on the skeletal chest is minimized, thus and as a consequence the rectus abdominis muscles inserting on the lower rib arches are also relaxed. These abdominal muscle insertions notably also have to be dissected or split longitudinally for the access to the rib cartilages along the inferior costal arch.

5.2.3 Positioning during surgery of other deformities

The positioning in other thoracic wall deformities depends on the necessity whether thoracoscopy is necessary or not. In all interventions, that come along without endoscopic access, the positioning with adducted arms is recommended in order to relax the thoracic cage and thus to facilitate the surgical preparation of the anatomic structures especially the muscles, but moreover to enable a proper anatomic repositioning of eventually detached muscle flaps from the sternum and adjacent ribs.

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5.3 Special anesthetic considerations in thoracic wall surgery: epidural anesthesia, lung separation, and postoperative analgesia

Günter Luckner, Gottfried Mitterschiffthaler, Martin W. Dünser

5.3.1 Introduction

According to North American data, the minimally invasive reconstruction of pectus excavatum (MIRPE) procedure is performed at an average patient age of 12.4 years [1]. In Europe, the corresponding mean patient age varies between 17.6 ± 5.8 and 15.1 years [2, 3]. Therefore, most anesthesias for the MIRPE procedure need to be performed in pupils and adolescents. In majority of the cases, the MIRPE procedure, as originally described by Nuss or as a combined semi-open approach in adults, is performed for idiopathic thoracic wall deformity, while some patients present with iatrogenic thoracic wall deformity (e.g., following cardiac surgery) or deformities secondary to connective tissue disease (e.g., Ehlers–Danlos or Marfan syndrome). Most patients with thoracic wall deformities do not exhibit substantial lung function deficits [1]. A history of exhaustion after limited exercise should prompt preoperative spirometric testing. Most commonly, those patients who show decreased lung function suffer from a restrictive ventilatory pattern.

Preoperative cardiologic workup is indicated only in symptomatic patients [4]. If thoracic wall deformity is present secondary to cardiac surgery, recent cardiologic reports should be checked and the administration of antibiotic prophylaxis considered to prevent endocarditis.

Patients with a keel chest deformity also undergo thoracoplasties with similar invasiveness to the skeletal structures thus suffering from postoperative pain. While in these patients, in contrast to the MIRPE or similar procedures, a conventional tracheal intubation is sufficient, postoperative pain control is necessary likewise to funnel chest surgery.

5.3.2 Pre-anesthetic consultation

During the pre-anesthetic consultation, a detailed medical history is taken. It is especially important to explore a history of abnormal bleeding or allergies. In underage patients, written informed consent is obtained from both patient and legal guardians. Patient information and medical history must be meticulously documented, especially concerning risks and benefits of invasive procedures such as epidural catheter and central venous line placement. In light of its paramount importance in postoperative pain management for major surgery at funnel and the keel chest deformities, placement of an epidural catheter should always be scheduled as long as there are no contraindications [5]. Awake puncture is considered feasible from age (10–)12 years, but should not be forced upon the patient, and should always be discussed with both the patient and his legal guardians. Adequate postoperative analgesia can also be achieved with continuous intravenous infusion of opioids, provided that appropriate monitoring is available [6].

Also discussed are airway management using double lumen tubes (DLTs), and the technique of ventilatory lung separation [7, 20, 21, 26]. Additional compulsory issues discussed during the preoperative consultation are specific invasive procedures such as a central venous catheter and arterial line, which are mandatory at our institution considering the potential complications for pectus excavatum surgery [8, 9]; these issues may be omitted for pectus carinatum surgery.

Erythrocyte concentrates should be readily available for transfusion. At our institution, we routinely have two units on hand. Routine preoperative laboratory tests include blood count, standard coagulation markers (partial thromboplastin time, prothrombin time), and serum biochemistry, but there is no evidence to support the use of these laboratory tests.

Postoperative care should be scheduled for the first 24 h to assure optimal monitoring, pain therapy, and mobilization.

Patients are free to ingest clear fluids until 2 h preoperatively, and two sites for venous puncture are primed using a eutectic mixture of local anesthetic (EMLA®) plasters.

5.3.3 Anesthesia

On arrival in the operating room, the patient is welcomed by the anesthetist and positioned on the operating table. The sensitivity of young patients undergoing this procedure is to be dealt with tactfully.

5.3.3.1 Thoracic epidural anesthesia

Thoracic epidural anesthesia is a segmental blockade of autonomous and somatic nerves with an upper and a lower sensory level. These levels need to be adapted for the particular surgical procedure. The advantages of thoracic epidural anesthesia do not substantially differ for adolescents and adults [10] and include excellent intraoperative analgesia without needing high-dose opioid administration, and the postoperative provision of continuous epidural analgesia [11–13].

General considerations for the loss-of-resistance method used at the mid-thoracic level

Good knowledge of vertebral column anatomy is essential in the performance of epidural anesthesia. The distance between the ligamentum flavum and the dura is approximately 2–3 mm in the higher thoracic region, and increases to 3–5 mm in the lower thoracic region. Spinous processes are angled almost horizontally at the cervical levels, and downward between 40° and 70° in the mid-thoracic region (Fig. 1). This angle, which may interfere with the median approach to epidural catheter placement, becomes less pronounced toward the lower thoracic levels [14].

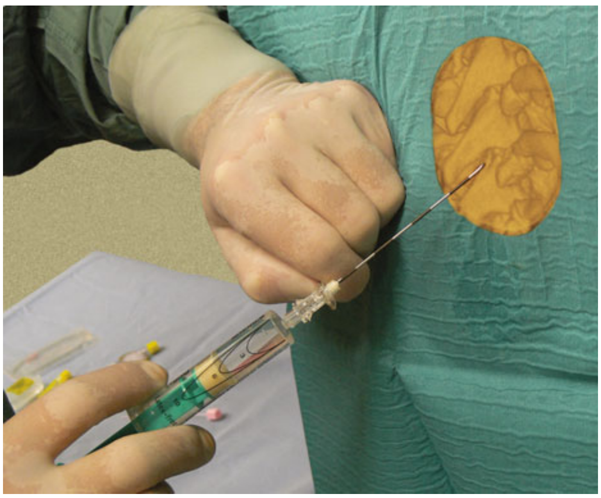

Fig. 1. The left hand is used to advance the needle and control its depth of penetration below the skin. The right hand is used to maintain pressure on the loss-of-resistance needle. Spinous processes are angled downward between 40° and 70° in the mid-thoracic region

The puncture level is determined primarily by evaluating osseous landmarks. Most importantly, a line connecting the lower scapular angles indicates the level of the seventh thoracic vertebra.

Before puncture, the skin and subcutaneous tissues are infiltrated with local anesthetic to permit pain-free epidural puncture. To ensure minimum discomfort for the patient during epidural puncture, it is important to allow sufficient time for the local anesthetic to take effect.

In children in whom an awake puncture is planned, the puncture area can be prepared using a local anesthetic cream or plaster (EMLA®).

Positioning and approach

Epidural catheter placement is performed in the monitored patient (pulse oxymetry, electrocardiogram, and non-invasive blood pressure) only after venous access has been established. Puncture is performed in a sitting position, with the patient bent forward, his elbows resting on his thighs, and his head bent down. This position helps bring the thoracic spine into a more lordotic position, facilitating epidural access.

The patient should be made aware that sudden movements may be detrimental. To ensure the patient's immobility, an anesthesia nurse supports the patient from anterior.

The puncture set for thoracic epidural anesthesia and the sterile gown for the anesthetist performing epidural anesthesia are prepared before the patient is brought into a sitting position.

In young schoolchildren under the age of 10–12 years, we perform the epidural access under general anesthesia in the left lateral decubitus position while gently flexing the patient's vertebral column.

The paramedian approach can be performed at all thoracic levels, whereas the median approach can be technically difficult or impossible between the levels of the third and ninth thoracic vertebra due to spinous process configuration. For this reason, we primarily use the paramedian approach.

Paramedian approach

We mark the central points of two adjacent interspaces between spinous processes, and draw a line connecting these points. From the mid-point of this line, the puncture site is found by moving 1(–2) cm laterally. The epidural puncture is performed at 15° toward the median sagittal plane, with the needle directed 50° cranial. The angles cited here are only approximate values that need to be tailored to the particular patient by the experienced clinician.

About 1 cm below skin level, the needle's stylet is removed, and the loss-of-resistance syringe filled with normal saline is connected to the needle. The left hand is used to advance the needle and control its depth of penetration below the skin. While the thumb and second finger of the left hand are used to advance the needle, the third to fifth fingers stabilize the needle against the patient's back. The right hand is used to maintain pressure on the loss-of-resistance needle, but does not assist in needle advancement (Fig. 1). The distance from skin to epidural space shows considerable interindividual variability, and is about 3–6 cm in adults. Therefore, loss of resistance may be encountered only after a few centimeters.

In children, the distance from skin to epidural space can be estimated using formulas originally devised for the lumbar epidural space. At birth, the distance between skin and lumbar epidural space is about 10 mm, and increases in a linear fashion with age. In older children, Busoni's formula is frequently used [(age in years × 2) + 10 mm)] [15]. It should be remembered, however, that these estimates are valid only for the lumbar epidural space, and are only rough indicators for the distances encountered in the thoracic region.

When the ligamentum flavum is penetrated, a sudden loss of resistance is perceived, both to needle advancement and to fluid injection.

On entering the epidural space, the catheter is threaded approximately 4–5 cm into it.

Before meticulous fixation of the catheter, intravascular or spinal misplacement should be ruled out. This is done by excluding passive reflux of blood or cerebrospinal fluid via the catheter and by attempting active aspiration using a small (2 cc) syringe. It should be noted, though, that even if reflux or aspiration of blood or cerebrospinal fluid is absent, intravascular or intrathecal catheter localization cannot be fully excluded.

5.3.3.2 Drugs and dosing for adolescents and adults

The volume of local anesthetic administered determines the number of segments blocked and therefore the longitudinal spread of epidural anesthesia. As an initial dose in adults and adolescents, we apply 1.0–1.5 ml of local anesthetic per segment. In children, we use 0.75 ml/kg body weight.

The concentration of local anesthetic is relevant to block density. Local anesthetic administered at low concentrations (ropivacaine 0.1%, bupivacaine 0.125%) primarily causes sympathetic and sensory blockade, while administration of local anesthetic at high concentrations (ropivacaine 0.2–0.5%, bupivacaine 0.5%) produces sufficient intraoperative analgesia and motor blockade. Local anesthetics used at higher concentrations are therefore beneficial, if intraoperative muscular relaxation is desired in addition to sensory blockade.

In the postoperative phase, small to medium concentrations of local anesthetic are used for analgesia, which should optimally spare motor function.

Addition of opioid to the local anesthetic has a synergistic analgesic effect and therefore permits the local anesthetic dose to be reduced.

The particular local anesthetic and its dosage are decided by the anesthetist performing the epidural puncture. A dose overview of commonly used local anesthetics is found in Table 1. In children, doses should be adapted and maximum allowable doses kept in mind.

As an initial bolus, we use 8–15 ml ropivacaine 0.2% (or bupivacaine 0.25%) plus 100 µg fentanyl. For intraoperative maintenance, we use a perfusion pump working at 6–10 ml/h. The perfusor may be prepared as

Table 1: Local anesthetics commonly used in epidural techniques under combined general and thoracic anesthesia – adults and adolescents (>50 kg)

Anesthetic	Concentration	Initial bolus	Intraoperative	Baseline rate for patient-controlled thoracic epidural analgesia (PCTEA)
Ropivacaine	0.2–0.5%	5–15 ml plus opiate: e.g. sufentanil 1 µg/ml or fentanyl 100 µg	Repeated dose: Half of the initial dose (approximately every 60–90 min) Continuous dose: 6–10 ml/h ropivacaine 0.2–0.5 %	Ropivacaine 0.2% + e.g. plus sufentanil 0.5 µg/ml: 5–7 ml/h; bolus 2 ml; lock-out time 20 min
Bupivacaine	0.25–0.5%	5–15 ml plus opiate: e.g. sufentanil 1 µg/ml or fentanyl 100 µg	Repeated dose: Half of the initial dose (approximately every 60–90 min) Continuous dose: 6–10 ml/h bupivacaine 0.125–0.5%	Bupivacaine 0.175% + e.g. plus sufentanil 0.5 µg/ml: bolus 2 ml; lock-out time 20 min

follows: 50 ml of ropivacaine 0.2% plus 100 µg fentanyl: 10 ml of ropivacaine 1% plus 2 ml of fentanyl (100 µg), plus 38 ml normal saline. This regimen permits 10–12 spinal segments to be blocked.

Spread of epidural anesthesia should be tested preoperatively. Spread beyond C8 causes sensory loss in the small finger, and diaphragmatic function is lost when local anesthetic blocks the fourth cervical nerves.

Safe practice of thoracic epidural anesthesia is assured only when the practitioner has a thorough theoretical knowledge of indications, contraindications, and potential complications entailed [16, 17]. Apparent or potential complications such as signs of epidural space compromise (motor weakness, backache, paresthesia, paralysis, cervical rigor, and headache) should be readily recognized and diagnosed by computed tomography (CT) or magnetic resonance imaging (MRI), and promptly managed. If epidural hematomas are not surgically decompressed within about 6 h, neurologic recovery is not likely. Knowledge of the mandatory intervals between administration of anticoagulants and insertion or removal of epidural catheters is imperative [18, 19].

Anesthetist experience with slow injection of local anesthetic under repeated aspiration after previous administration of a test dose containing adrenalin is also a prerequisite.

5.3.3.3 General anesthesia

After thoracic epidural anesthesia has been initiated, the patient is brought into a supine position. For induction of general anesthesia, we use propofol 2.5–3.5 ml/kg body weight, fentanyl 3 µg/kg body weight, and rocuronium 0.6 mg/kg body weight. Complete muscle paralysis is verified using a peripheral nerve stimulator. Intubating conditions should be optimal when airway management is performed using a DLT, because the risk of injury is considerably increased when this device is used [20] but most of the complications encountered with double lumen tube placement (malposition, tracheobronchial tree disruption, and traumatic laryngitis) can be avoided by multiple repeatedly checkings on tube position and by selection of appropriately sized tubes.

Intubation using a DLT allows for ventilatory lung separation [21]. During the Nuss procedure, the main indication for separate lung ventilation is the optimization of surgical conditions. Experience in device handling and tracheobronchial anatomy are essential to safely perform DLT insertion. We use the PVC Robertshaw model with no carinal hook (Broncho-Cath™ MALLINCKRODT). For thoracoscopic and extrapulmonary surgery, left-sided DLTs are generally recommended. These are available from size 26–41 Ch. The tracheal diameter is considered a good indicator for DLT size [22, 23]. In children under the age of 8–10 years and in small adults, lung separation can alternatively be performed with a bronchial blocker or deliberate left-sided intubation using a conventional endotracheal tube. The smallest available DLT has a size of 26 Ch, corresponding to an endotracheal tube with an internal diameter of 6 mm.

Approximate size of DLT for adults:

- 35 Ch: <165 cm height,
- 37 Ch: 165–175 cm height,
- 39 Ch: 175–185 cm height,
- 41 Ch: >185 cm height, and
- smaller available sizes: 26/28 and 32 Ch.

Patient positioning and DLT intubation: For intubation, the patient's head is brought into a Jackson position, while the entire patient is brought into a 15° reverse Trendelenburg position. The patient's teeth are protected with a gumshield. After laryngoscopic visualization of the vocal cords, the left-sided DLT is advanced into the trachea with the distal tip facing anterior. Subsequently, the DLT stylet is removed, and the tube rotated 90° counterclockwise. Now, the tube is gently advanced until an elastic resistance is encountered. When using a left-sided DLT, this is usually elicited by fixation of the distal bronchial tube in the left main bronchus. Now, the proximal (tracheal, transparent) cuff is blocked first. To estimate depth of tube insertion, the distance between the middle of the clavicle and the carina can be measured on a chest radiograph [24]. The gold standard, however, is fiberoptic verification of DLT position [25, 26]. Introduction of the flexible fiberscope is possible via a universal adaptor (Mainzer Universaladapter®, Rüsch, Waiblingen). To this end, the DLT's tube adaptor is clamped proximally on its tracheal limb, and the bronchoscope is inserted into the tracheal tube. When the tracheal bifurcation and both main bronchi are visualized, the anesthesia nurse blocks the distal (bronchial, blue) tube in the left main bronchus. The tip of the flexible fiberendoscope is positioned in the distal orifice of the tracheal lumen to allow visualization of the DLT (Figs. 2 and 3). The figure shows the correct position of the bronchial (blue) cuff just beneath the tracheal carina in the left main stem bronchus, with unobstructed view of the carina itself. To inspect DLT position, a fiberendoscope with an outer diameter of 3.6 mm is used. This endoscope allows verification of position in DLT down to a size of 35 Ch. For smaller DLT

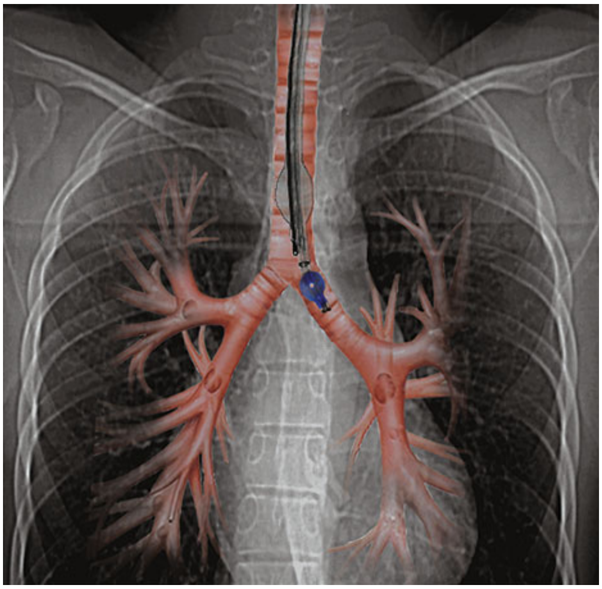

Fig. 2. Depicts fiberoptic verification of left-sided DLT position via the tracheal lumen, with correct position of the tracheal (transparent) and bronchial (blue) cuffs

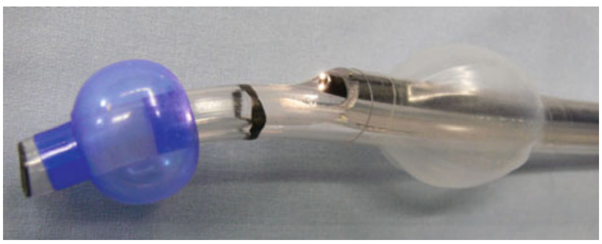

Fig. 3. The tip of the flexible fiberendoscope is positioned in the distal orifice of the tracheal lumen to the DLT

size 26–32, an ultra-thin fiberendoscope with an outer diameter of 2.2 mm should be used. When the DLT is correctly positioned, the inflated bronchial cuff can be seen as a narrow blue crescent on the medial side of the tracheal bifurcation. The DLT should be secured in this position. However, in our opinion, the best method for placing DLTs on first try was first described in 1996 by Ovassapian. For this technique the tube is first advanced only into the tracheal lumen. Then the fiber endoscope is moved through the endobronchial lumen, until the carina and mainstem bronchi are identified. Next, the endoscope is advanced into the proper bronchus and, using it as a stylet, the DLT is slid over the fiber endoscope until the bronchial lumen comes into sight ahead of the tip of the fiber endoscope. Finally, the fiber endoscope is moved through the DLT's tracheal lumen

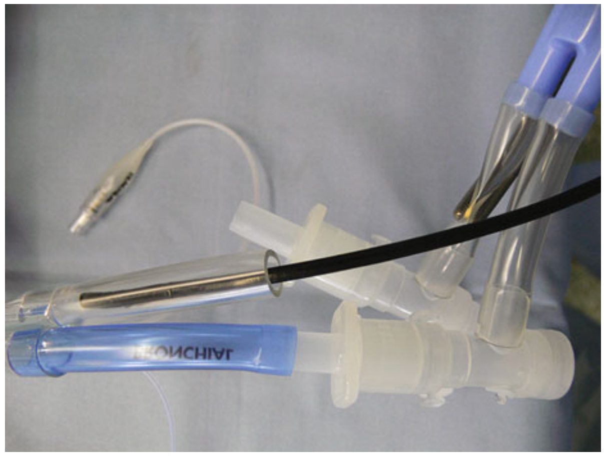

Fig. 4. Introduction of the flexible fiberscope in the proximal limb of the right limb of the tube connector, and disconnecting the distal limb of the DLT

to confirm that the position of the DLT is correct [27]. DLT stability can be enhanced by inserting an additional Guedel tube. To exclude dislocation of the DLT (e.g., herniation of the distal cuff into the trachea), the position should be repeatedly verified, especially after each change in patient position and whenever oxygenation seems impaired.

Immediately before the surgeon enters the thoracic cavity, lung ventilation should be separated by clamping the proximal limb of the left or right limb of the tube connector, and disconnecting the respective distal limb (Fig. 4).

After DLT placement, a central venous catheter may be inserted under ultrasound control via the subclavian or internal jugular vein. A Foley catheter should be placed to monitor urine output during surgery. After cannulation of the radial artery, the anesthetic procedures are completed.

Specific anesthetic responsibilities during surgery include routine verification of patient position, DLT position, and temperature management. Anesthesia can be maintained by continuous infusion of propofol (1%, 30–50 ml/h) and low-dose remifentanil (0.05–01 µg/kg/min), the latter to provide analgesia for positioning and tube tolerance.

Intraoperative fluid substitution is performed using crystalloid solutions. For moderate surgical trauma, approximately 3–5 ml/kg body weight/h is infused. The rate of infusion and the type of solution (crystalloid versus colloid) need to be adapted to surgical progress and the extent of surgical trauma [28] and necessitate continuous communication between surgeon and anesthetist.

During one-lung ventilation, inspiratory oxygen concentration is initially increased to 100%, and later adapted to periodic blood gas analyses. The standard ventilator setting for one-lung ventilation is approximately the same tidal volume as for two-lung ventilation (10 ml/kg). Respiratory rate is adjusted to maintain normal $paCO_2$ [29]. Nitrous oxide is not used during one-lung ventilation or thoracoscopy. At the end of surgery, the patient should be promptly extubated.

5.3.4 Postoperative patient management

Owing to the nature of surgery, pain management is the most important postoperative concern. Continuous epidural infusion of local anesthetic is the method of choice, and the patient should be regularly evaluated for block level, sufficient pain control, and adverse events. Quality of pain therapy is evaluated using a 0–10 Numeric Pain Intensity Scale.

The standard epidural infusion at our institution is 0.2% ropivacaine combined with 100 μg fentanyl (in 50 ml normal saline), administered at 6–10 ml/h.

After the patient is transferred from the postoperative intermediate care unit to the normal ward, epidural infusion is continued in the form of patient-controlled epidural anesthesia (PCEA) under the supervision of the institutional pain service. The epidural catheter should be checked regularly for signs of infection and removed between the third and fifth postoperative day.

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5.4 Video-assisted thoracoscopy (VATS)

Paolo Lucciarini, Anton H. Schwabegger, Thomas Schmid

5.4.1 Introduction

Since the introduction of video-assisted thoracoscopy (VATS), this endoscopic procedure has evolved to a safe, standardized treatment supporting modality also for the minimally invasive repair (MIRPE) of congenital thoracic wall anomalies, namely for the surgical treatment of pectus excavatum deformity, nowadays performed in numerous specialized surgical referral centers.

The minimally invasive placement of one or two individually formed metal struts for reshaping a sunken sternum with its adjacent ribs was initially described by Donald Nuss in 1998 (Chapter 6.3), remarkably after a follow-up period and cumulative experience of 10 years [1, 2]. Concomitantly with the general technical development of video-assisted thoracoscopic equipments and increasing knowledge in thoracoscopic operations, such as minimally invasive apical lung wedge-resections or evacuation of thoracic empyema exemplarily, the MIRPE was developed. Pediatric and reconstructive surgeons likewise [3–5] adopted endoscopic assistance and control of instruments or pectus-bar hardware implantation in pectus excavatum surgery. Its routine use led to a marked reduction of intraoperative complications, which are assumed but not reported along with the first series of the MIRPE interventions. At that time, the pioneer surgeons performed pectus-bar implantation yet without assistance of an intraoperative thoracoscope. Such complications were injuries of lung parenchyma due to pre-existing pleural adhesions with subsequent air leaks and/or hemorrhage, bleeding from intercostal or internal thoracic vessels [6] during forced placement of the metal bars, with shearing and disruption effects on intrathoracal tissue or improper placement of the metal strut with late sequela. In exceptional cases, life-threatening events and fatal outcome had also been described only recently, mostly because of injury to the heart and/or great vessels after uncontrolled hardware insertion or removal maneuver [7–14].

In particular, the assistance of VATS in the MIRPE of adolescents or adults is of paramount importance, since all thoracic wall structures at that age feature much more rigidity than those in children. Because of such restricted mobility of the anterior thoracic wall, narrowed and rigid space for surgical maneuvers due to the immobility of the sunken sternum and adjacent ribs is usually existent in adults, notably in athletic males. Therefore the endoscope is an utterly necessary tool to provide with survey and a safeguard against potential intrathoracal tissue damage during implantation of instruments and final placement of the pectus bar.

5.4.2 Surgical technique

The patient is placed in a slightly overextended supine position with a foamy pad underneath the shoulders for proper exposition of the sunken sternum and deformed anterior thoracic wall. The arms are abducted 90° from the trunk (Figs. 1 and 2) on both sides to improve maneuverability of the videoendoscopic system, with attached camera, hooked light cable and electronic wires. Double-lumen tracheal intubation (Chapter 5.3)

Fig. 1. Positioning of the patient for videoendoscopic access. Arms are abducted with flexion at the elbows to gain sufficient place for both the pectus-bar implantation and the endoscopic maneuvers, postoperative view, notice the double-lumen tracheal tube

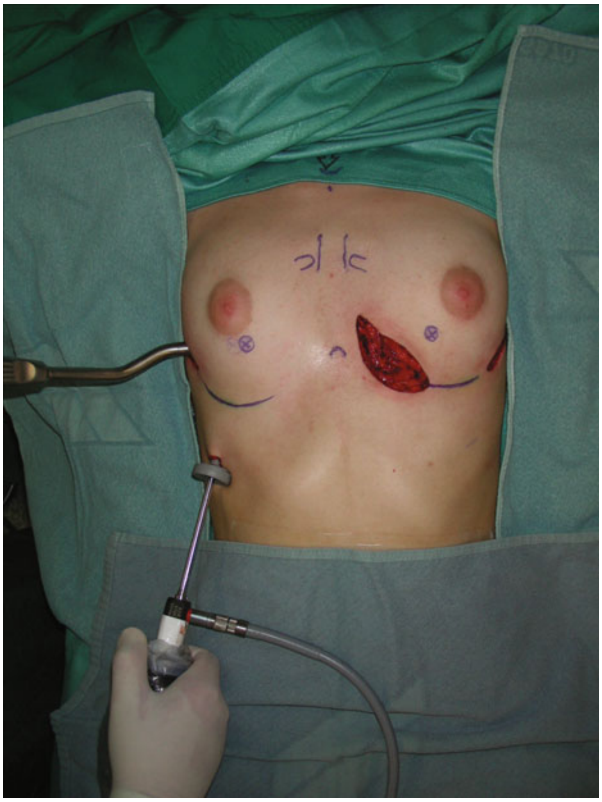

Fig. 2. Intraoperative situation with the endoscope and the pectus-bar flipper in place. This is a modified semi-open approach with thoracotomy and necessary osteochondrotomy in a young female adult with a rigid and deep deformity

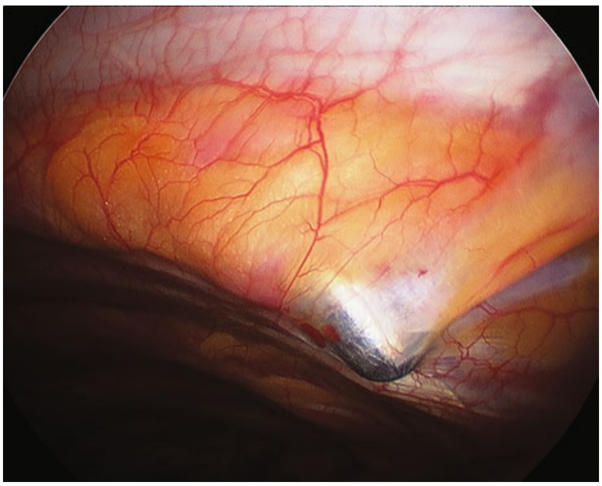

Fig. 3. Endoscopic view of the right pleural space and deflation with blocked right unit of the double-lumen tube. The round dissector appearing at the intercostal space prior to perforation of the parietal pleura

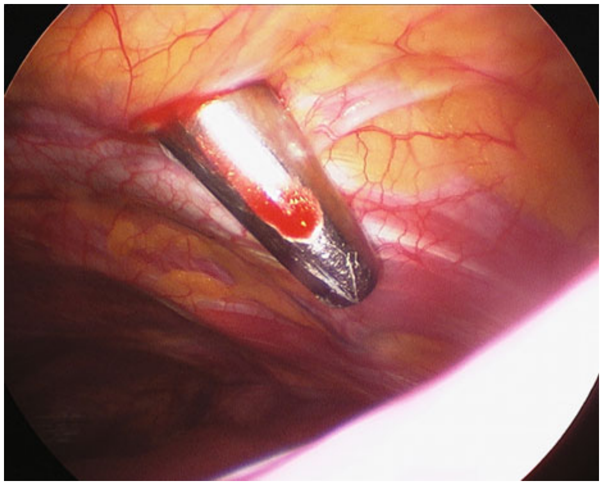

Fig. 4. Same view as in Fig. 3, immediately after perforation of the parietal pleura. Notice almost no bleeding due to the blunt dissection with the aid of the round tunnelizer

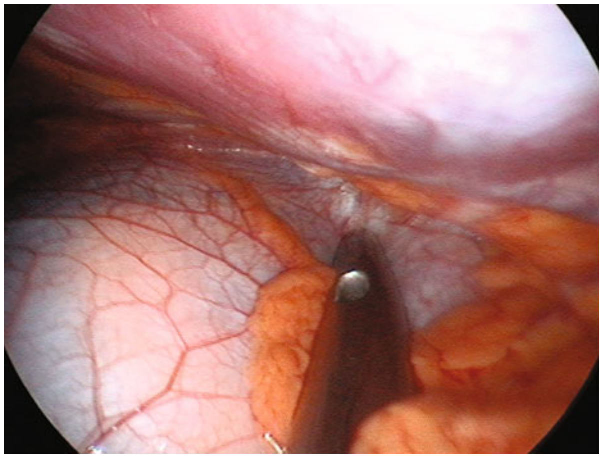

Fig. 5. Blunt preparation of visceral pleura and lung at the right side toward the mediastinal fat and pericardium

especially in adults is mandatory and during setting of the thoracoscopic ports on either side of the respective lung is excluded from ventilation. This setting allows a careful and entire exploration of the respective pleural cavity and blunt dissection with or without electrocautery of eventual adhesions between the visceral and the parietal pleura under controlled intraoperative visualization (Figs. 3–8).

According to our experience, the use of a 5 mm/30° angled optical system is sufficient for a complete exposure of both pleural cavities, also on the left side where occasionally the heart, usually displaced by

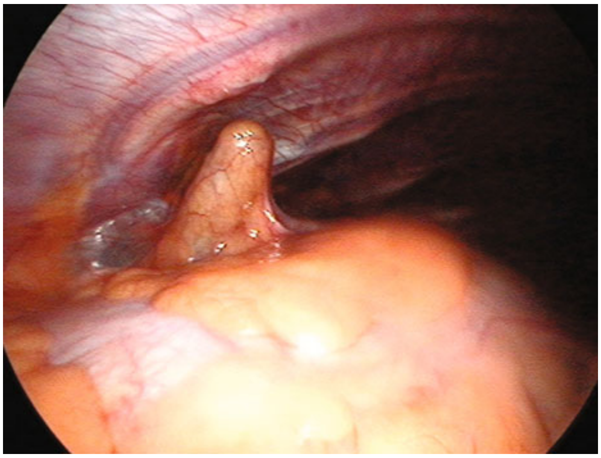

Fig. 6. The round tip of the tunnelizer appears at the left side with some pericardial fat elevated. The endoscope now is introduced at the left side, with the right lung inflated and the left lung deflated

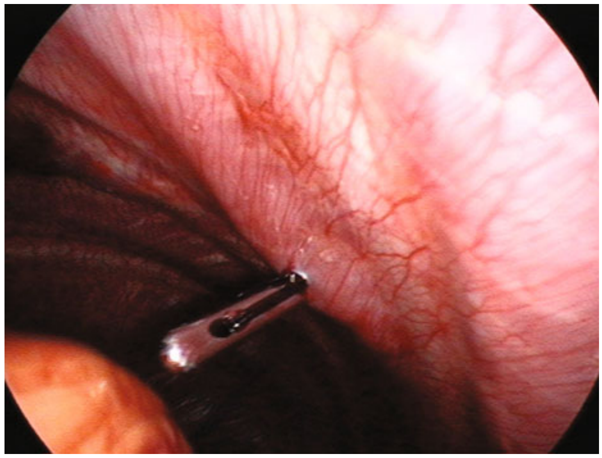

Fig. 8. Endoscopic view at the left lateral thoracic wall, depicting the threaded Deschamps-awl containing a strong suture for circumcostal fixation of the lateral pectus-bar end

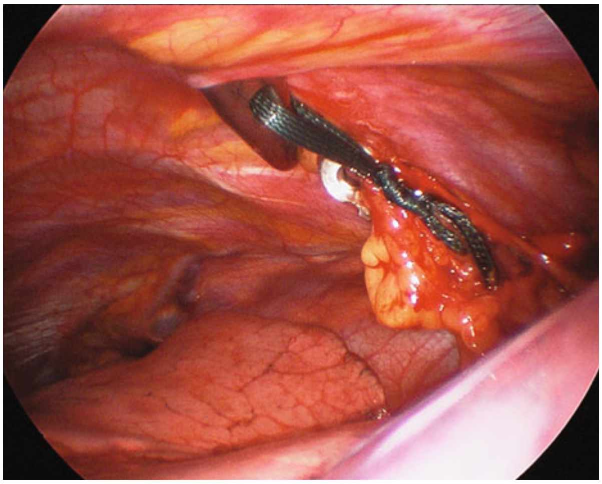

Fig. 7. The situation demonstrates a potential complication with trapped pericardial fat at the pectus bar during implantation and pull through. View at the right pleural space, immediately prior to slipping through the right thoracic wall

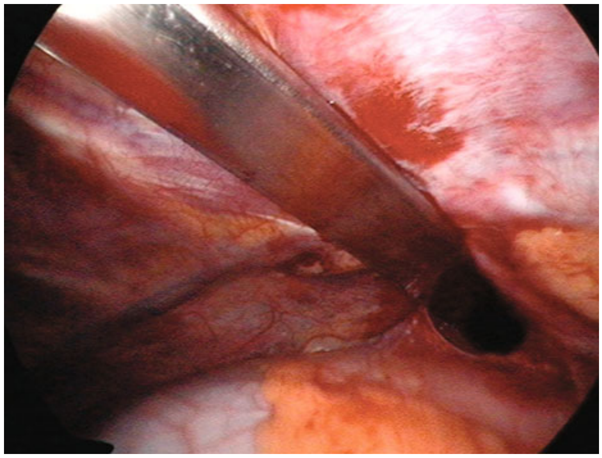

Fig. 9. Right pleural cavity with the pectus bar perfectly in place. The internal thoracic vessels (running from the center of the picture to the bottom left) remain undamaged

the sunken sternum, may render a sufficient overview more difficult. Also, 30° angled optics much easily enable the observation of the thoracic wall from the intrathoracal aspect during insertion (Figs. 4 and 5) and passage of the dissector or the pectus bar, guiding its retrosternal passage maneuver (Fig. 5) between the posterior aspect of the sternum and the heart within the prepericardial fat pad (Fig. 6). In addition, the phrenic nerve may clearly be identified and preserved as the dissector and pectus bar pass ventrally to it.

Subsequently implantation of the shaped pectus bar firmly attached to the applicator from one to the other side is also performed under thoracoscopic view (Fig. 7), allowing eventual adjustments of bar position during this maneuver and minimalizing any risk for injury to adjacent structures and intrathoracal organs. In the case of stabilization of the pectus bar utilizing circumcostal sutures, the passage of the threaded Deschamps-awl between the ribs may accurately be visualized (Fig. 8) to avoid damage to the lung surface. Finally the correct position of the placed pectus bar is controlled via endoscope (Fig. 9) and potential bleedings or injuries to the intrathoracal organs may be detected in due time.

Additionally and in contrast to 0° non-angled optics, the flexibility of 30° angled systems is superior concerning general intrathoracal overview and an extended survey may be achieved just by simple rotation of the optics along its longitudinal axis into the direction of interest.

Two small skin incisions not extending 5 mm and in accordance with Langer's cutaneous lines are made on either side of the thorax, preferably at the eighth or ninth intercostal space, at the extension line of the anterior axillary fold (Fig. 2). Subcutaneous and muscle planes are divided with small scissors and blunt perforation of the parietal pleura is then obtained, using a small clamp and after alternating exclusion of ventilation on either side in close cooperation with the anesthetist utilizing the technical properties of a double-lumen tracheal respiration tube (Chapter 5.3). Thereafter, a 5 mm trocar–port is inserted through the same incision and screwed into the pleural cavity. Care must be taken to place the incisions and trocars on the superior margin of the rib to avoid subcostal damage to intercostal vessels and/or nerves with potential cumbersome neuralgia. In addition, a symmetrical alignment of both 5 mm cutaneous trocar-port incision sites should be aimed at for aesthetic reasons.

Gas insufflation during videothoracoscopy is not necessary since the pleural space is very well accessible after ventilation exclusion on the respective side, when a double-lumen tracheal tube is used and thus temporary collapse of the right or left lung is obtained. Because the left main bronchus is anatomically longer than the right one, usually a "left-sided" double-lumen tube is used by the anesthesiologist to perform alternating and separated ventilation of right or left lung effectively.

Usually, there is no need for routine insertion of a chest drainage tube ensuing the surgical procedure, except for a potential collection of fluid or blood after placement of the bar(s), or when an air leak at the lung parenchyma is evident. In these cases, a 16 Charriére chest tube generally is sufficient for effective postoperative fluid evacuation and/or management of parenchyma air leakage. It is inserted through the initially performed 5 mm port incision, and fixed to the skin by strong sutures. After radiologic chest control the chest tubes may be removed on the second or third postoperative day depending on the extent of fluid and/or air output through the drainage. The patient is asked to hold breath in expiration and the thoracic drainage is then quickly removed, a swab with disinfectant ointment is subsequently applied at the orifice to avoid air aspiration during drain removal. As an alternative, an air and liquid tight, transparent adhesive tape may be placed instead of the sterile swab, which enables visibility and direct control of the small wounds. The patient should thereafter rest in bed for 1 h with a firmly attached wound dressing. In the asymptomatic patient chest radiographic control is done only on the following day.

As mentioned above, potential complications like intraoperative hemorrhage may be detected early, when VATS is routinely used during the MIRPE. Therefore, a basic thoracotomy emergency set should be available in the theater at any time during surgery, including thoracic rib–retractors of different dimensions depending on patient age, vascular clamps, and lung grasping forceps. Thus, successful and early management of potential intraoperative complications may be achieved, either by continuing in VATS or conversion to open thoracotomy approach if necessary in major problems.

All these aspects have to be considered and discussed with the patient preoperatively in detail, when selection for the pectus-bar implantation is indicated, information about the planned surgical procedure is offered, and signing of informed consent is arranged. Particularly, rare but potential intraoperative hemorrhage due to damage to greater vessels or heart has to be mentioned. Eventual intraoperative surgical complication management, with necessary extension of the minimally invasive access or even conversion to open surgery must be explained to the patient accurately.

5.4.3 Conclusion

Nowadays the routine use of intraoperative videothoracoscopy in the MIRPE has to be strongly recommended in specialized referral centers for surgical treatment of extensive funnel chest deformity. Preferably, and especially in adolescents or adults, the videothoracoscopy should be performed by a thoracic surgeon, who is familiar with the use of such videoendoscopic equipment during standard and complex operations in general thoracic surgery. This surgeon should be able to recognize potential intraoperative complications (Fig. 7) during the pectus-bar implantation, and must be capable and be trained to manage such complications. That is why an interdisciplinary approach is strongly recommended especially in the cases with a higher prevalence to complications, which rather likely occur in elder adolescents and adults [14]. Furthermore this need for interdisciplinary expertise and, in contrast to other routine surgery, the lower number of pectus excavatum cases that are treated, are strong arguments for focussing the selection, indication setting, and performance of surgery as well as after treatment to specialized referral centres, experienced with a sufficient high number of cases treated per year.

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