Anterior Scoliosis Surgery: Current Role

Ramachandran Govindasamy, Vishnu Prasath CS, and Yogesh Kumar

1 Introduction

The posterior approach for scoliosis has replaced anterior surgeries because of the ease of access, various osteotomy techniques, powerful pedicle screw constructs, and modern instrumentation available for scoliosis maneuvering. However, there has been a resurge in interest in anterior scoliosis surgeries among present-day surgeons because of its inherent advantages, such as better correction, fusion, and paraspinal muscle sparing. In addition, there has been a development of less invasive anterior approaches to deformed spines in the form of video-assisted thoracoscopic surgeries (VATS). Fusion surgery gives reasonably good correction and reduces further worsening of the deformity, but the spinal motion is also impaired. This spinal mobility is of utmost importance, especially in adolescents and younger populations, for better flexibility without activity limitations and adjacent segment degenerations. A nonfusion surgical technique will be a game changer in pediatric scoliosis surgeries.

This chapter is designed and written for readers to understand the various anterior surgical options for pediatric scoliosis. It will be discussed under the following headings: history of anterior scoliosis surgery, surgical approaches, techniques, indications, contraindications, preoperative planning, literature review, tips, and pitfalls.

R. Govindasamy (✉)
Sakra World Hospital, Bangalore, Karnataka, India
e-mail: mail2ram8544@gmail.com

V. P. CS
SKS Hospitals, Salem, Tamil Nadu, India

Y. Kumar
Soundarapandian Bone and Joint Hospital, Chennai, Tamil Nadu, India

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2 History of Anterior Scoliosis Surgery

In the same decade as the 1960s, when Harrington from the USA was working on posterior instrumentation for scoliosis, Alan Dwyer from Australia successfully introduced anterior scoliosis correction surgery using cable and screw instrumentation. Even though he succeeded in correcting the frontal plane deformities, he could not address the axial rotation and sagittal correction and sustained the correction during follow-up. Zielke introduced the ventral derotation spondylodesis system (VDS) in 1973 using semirigid solid threaded rods and screws. He could successfully address the axial plane of deformity with the "Lordosator," a derotator device. He had better fusion and correction rates than Dwyer, but the problem of kyphosis persisted. Furthermore, research in implants and instrumentation led to better fusion rates by using stiffer rods, double rods, L plates, structural grafts, cages, etc. and correction using advanced instrumentation to perform cantilever, derotation, compression/distraction maneuvers, such as the KSS system Cotrel–Dubousset Hope (CDH), Texas Scottish Rite System (TSRS), and ISOLA system. The single-rod systems used in the past are Dwyer, Ziekle, Isola, TSRH, and BWM (Bad Wildungen Metz). The double rod systems most popular were Cotrel-Dubousset (CDH) and Kaneda (KASS system). Recently, L plates were designed and used to avoid instability issues at upper and lower instrumented vertebrae.

3 Surgical Approaches

Anterior Approach to Thoracic Curve

The patient is placed (Fig. 1) on a hinged table (hinge at the apex of the curve) in the lateral decubitus position with the convexity of scoliosis up. The hips are slightly flexed to take pressure off the lumbosacral plexus and reduce tension on the psoas muscle. The pelvis is secured by a hip rest and a large gel roll to eliminate intraoperative motion. General anesthesia without muscle relaxation is utilized for IONM. Double lumen intubation is used to deflate the ipsilateral lung in the case of thoracotomies for better exposure of the thoracic and L1 vertebral bodies.

The important sequential steps of an anterior approach to a scoliotic spine are as follows:

1. The pleural cavity is accessed via the rib attached to vertebra two above the apical vertebra. A cranial rib is better chosen because it allows easy retraction of the ribs caudally rather than retracting the rib cranially. The incision lies along the length of the rib, curving cranial posteriorly and caudal anteriorly. After subcutaneous dissection, the latissimus dorsi and serratus anterior muscles are split in the same direction, exposing the rib.

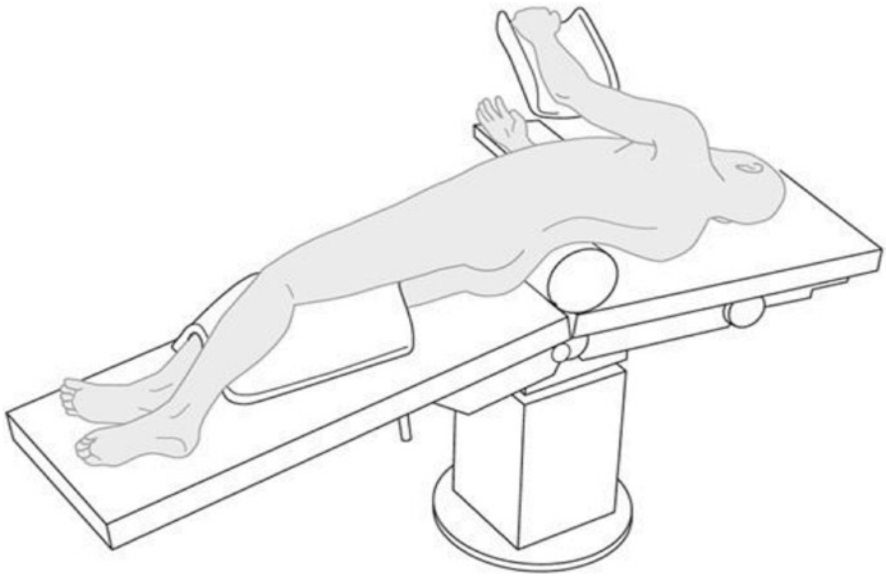

Fig. 1 Lateral decubitus position

2. Once the rib is exposed, the periosteum is lifted, allowing access to the upper border of the rib and the intercostal groove running along the inferior rib border. A Cobb instrument is used to elevate the periosteum from the superior border of the rib by moving the Cobb from posterior to anterior, and the intercostal neurovascular bundle is dissected off the intercostal groove.
3. The Doyen elevator is passed around the rib within the periosteum. It is used to free the periosteum from the medial border of the rib. It is best to pass this from inferior to superior, so the intercostal bundle is not caught under the elevator. The ultimate care should be taken not to plunge through the deeper layer of the periosteum into the pleural cavity as the elevator is passed under the rib since that could damage the lung parenchyma.
4. A ring costotome is used to excise the rib of 12–15 cm (Fig. 2a). The blade is used to cut the rib as posteriorly as possible—this will allow easier access once you reach the spine. The anterior rib is then divided around the costochondral junction. For the higher ribs, we can cut slightly lateral to the costochondral junction. Bone wax can be used to prevent ooze from the cut ends. Leaving sharp ends on the rib remnant could puncture the lung and hence, to be taken care.
5. The intact periosteum, which lies deep in the rib along with the parietal pleura, is then lifted using two pairs of forceps and divided. Dissecting scissors are used to free adhesions to the visceral pleura, and the periosteum along with the parietal pleura is cut in line with the rib (Fig. 2b). Lung injury should be avoided at this step, as it can cause air leakage. In the case of accidental injury, the hole needs to be sutured or a chest tube on low-level suction is kept to prevent ongoing pneumothorax postoperatively.

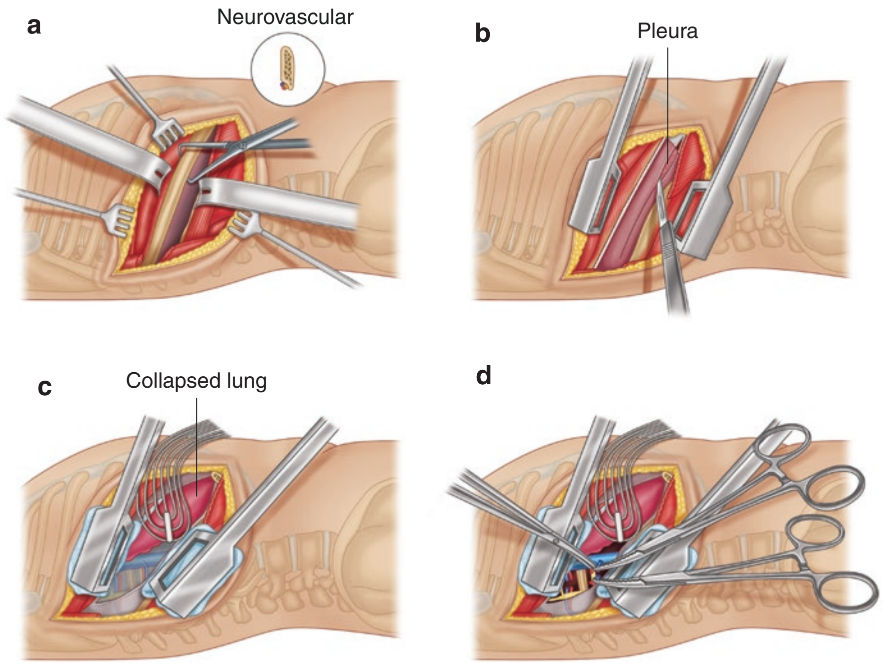

Fig. 2 Anterior thoracic surgical approach. (**a**) Exposed rib excised with costotome. (**b**) The parietal pleura opened with a sharp knife. (**c**) Collapsed lung retraction. (**d**) Segmental vessel ligation

6. The lung is exposed and compressed down and protected using a damp large swab. The use of a double-lumen endotracheal tube facilitates the collapse of the lung at this step. A Finochietto retractor is used to distract the adjacent ribs (Fig. 2c).
7. The spine is now visible. The surrounding structures at risk are:

   - The segmental vessels will lie transversely over the vertebral bodies.
   - The sympathetic trunk will be passing longitudinally down the spine.
   - The azygos vein passes up the right-hand side of the thoracic spine and loops over to drain into the superior vena cava level with T4.
   - The inferior vena cava also passes up the right-hand side of the spine.
   - The aorta passes down the left side of the spine but with severe rotational deformity, which can lie anteriorly or even on the right side of the thoracic spine.
   - The mediastinum and hilar vessels will lie anteriorly.
   - The diaphragm will be seen caudally.

8. The parietal pleura over the spine is lifted using forceps and divided using a scalpel. Scissors are then used to divide the pleura proximally and distally. The discs will be seen as the elevated parts of the spine (the “mountains”) and the

bodies as the "valleys.' The segmental vessels lie in the middle of the vertebral body passing anterior to posterior and can be ligated if needed (Fig. 2d).

Alternatively, a double thoracotomy can be performed four intercostal spaces apart inside the same incision to facilitate easier access to longer fusion segments. Following the desired procedure, such as release, with or without instrumentation, the parietal pleura over the spine may be closed using Vicryl. An incision for the chest drain is made just anterior to the mid-axillary line.

Anterior Approach to Thoracolumbar/Lumbar Curve

The positioning is similar to that described for the MT curve, commonly with the left convexity above.

The incision is made centered over the apex of the lumbar scoliosis curve and is usually made along a rib that generally attaches 1 or 2 vertebrae above the UIV. It should extend across the costochondral junction and turn obliquely anterior toward the lateral border of the rectus abdominis muscle (Fig. 3a). Usually, Lenke 5 and 6 curves will need the removal of the 10th, 11th, or 12th rib. Rib resection allows exposure of 5–6 vertebrae. Superficial dissection is similar and requires an incision of the latissimus dorsi. The selected rib is resected for a length of 15–20 cm, respecting the neurovascular bundle.

The deep dissection at the level of the TL junction consists of three segments (Fig. 3b, c)

1. In the posterior segment, the dissection is purely thoracic, and the parietal pleura is incised as described previously.
2. The anterior part of the deep dissection involves the dissection of the three muscle layers of the abdomen (along the direction of their fibers) to reach the retroperitoneal cavity. The lumbar spine is then reached by blunt dissection of the peritoneum using swiping movements of the fingers.
3. The deep dissection in the middle segment (which has the diaphragmatic attachment to the chest wall) is completed by connecting the anterior and posterior third. The inferior surface of the diaphragm is swept down off the peritoneum and taken down to the spine (down to the crus) from the chest wall, leaving behind a 1 cm margin around the periphery for later reattachment.

The diaphragm and peritoneum (below L1) are retracted anteriorly, whereas the psoas muscle is retracted posteriorly to expose the lumbar vertebrae. The parietal pleura is incised over the lower thoracic vertebrae above L1 up to the UIV. The segmental vessels are exposed and ligated similarly, and the sympathetic trunks are bluntly retracted (Fig. 3d).

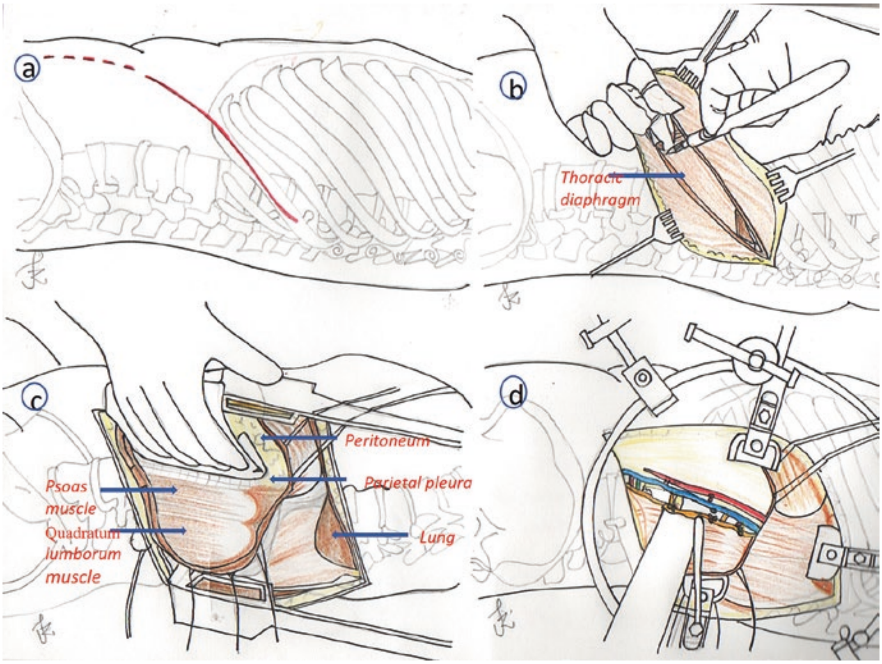

Fig. 3 Anterior TL/L exposure. (**a**) Skin incision along the T10 rib. (**b**) The diaphragm opened after a T10 rib excision. (**c**) Retroperitoneal dissection. (**d**) Exposed vertebrae with overlying segmental vessels

4 Anterior Scoliosis Surgeries

The indications for scoliosis fusion surgery are when a major curve Cobb angle is more than 40–45° in adolescents and 50° in adults. The other indications include truncal shift, significant cosmetic concerns even with a lower Cobb angle, and documented progress of the deformity. In scoliosis, whole-spine standing radiographs, PA and lateral views, and supine-assisted side-bending radiographs are performed as part of the preoperative evaluation for scoliosis surgeries. In selected cases, fulcrum bending and supine traction radiographs are taken to identify flexibility. The Cobb angles of major and minor curves are recorded with the upper and lower end vertebrae (UEV, LEV) in standing radiographs, and the curve is classified based on Lenke types. The other parameters, such as kyphosis, apical vertebral translation, rotations, and the Risser grade, were noted. The neutral vertebrae (NV), stable vertebrae (SV), and upper and lower instrumented vertebrae (UIV, LIV) are identified and planned accordingly for anterior/posterior procedures.

The three anterior surgical scoliosis surgeries that are performed by open/thoracoscopic techniques are as follows:

1. Anterior release procedures with posterior instrumentation for severe and rigid curves.
2. Stand-alone anterior scoliosis correction and instrumented fusion.
3. Anterior vertebral body tethering.

Anterior Release Procedures with Posterior Instrumentation for Severe and Rigid Curves

Severe and rigid scoliosis is defined as one where the Cobb angle exceeds 80° and with flexibility below 40% [1–5]. These curves usually need circumferential releases in the form of anterior release and posterior multilevel osteotomies, in addition to a powerful anchor such as pedicle screws for a favorable outcome. The anterior release usually involves the removal of discs at the apex and periapical levels in addition to rib heads.

Indications and Contraindications

A severe and rigid scoliotic curve that has a rounded configuration and is hypokyphotic (thoracic level) in nature is an ideal indication for anterior release procedures. A posterior approach following anterior release is needed to have a good anchor for manipulation and posterior osteotomies and to correct the other compensatory structural curves. In contrast, rigid scoliosis with sharp angular deformities does not greatly benefit from anterior release and is best approached by posterior three-column osteotomies with instrumentation [6]. Patients with a higher chance of pseudoarthroses, such as syndromic scoliosis and neuromuscular scoliosis, can also benefit from anterior procedures because of the availability of larger fusion area surfaces. Patients with pulmonary compromise, visceral abnormalities, retroperitoneal adhesions, and situations where anterior approaches can be deleterious are usual contraindications.

Surgical Technique

The anterior approach to the spine is the same as described in the earlier part of the chapter, following the exposure of the spine.

1. Annulotomy is made using a sharp 15 mm blade. Once the annulus and anterior longitudinal ligament are elevated, pituitary rongeurs are used to excise the disc. The spine is rotated due to scoliosis, and hence, one will be working toward the

neural structures in the spinal canal. Hence, utmost care should be taken not to plunge and always visualize the instrument tip.

2. A Cobb elevator instrument was used to lift the cartilaginous endplate off the bony endplate. Holding the Cobb elevator with both hands to allow careful dissection without plunging or slipping can avoid spinal cord and nearby vessel injury. The bony endplates are curetted to allow access to the cancellous bone for fusion. Curettage is performed with controlled rotational movement. With the exposed cancellous bone, the disc space can be packed to reduce bleeding while the rest of the procedure is completed.
3. The rib head is then exposed down to the rib neck by elevating the pleura further posteriorly. The neural foramen lies deep in the rib head. Care should be taken to avoid injuring the intercostal nerve and vessels that will be coming together inferior to the rib. Excising the rib head allows access to the posterolateral disc space so that more discs can be removed to allow further release. Detaching the rib heads removes the restrictions that the thoracic wall places on the spine, thereby increasing flexibility after the anterior release.
4. An osteotome is used to divide across the rib neck. The remaining levels are approached, and a discectomy with rib head excision is performed. Between four and six spinal motion levels can be released depending on the size of the curve and the flexibility of the ribs.

Review of Literature

The anterior release done through open thoracotomy or by a thoracoscopic approach can lead to a 141–288% increase in axial rotation in comparison to an 8.8–71.9% increase achieved by a posterior release. This increased mobilization of the vertebrae helps maximize the three-dimensional correction [7–9]. Following the anterior release, posterior correction and fusion can be either staged or performed in a single sitting based on the patient's pulmonary function and the spine surgeon's preference. Traditionally, anterior release and posterior instrumentation were staged to give time for the patients to recover between the surgeries. In their study [6] of staged anterior release and posterior instrumentation for severe rigid round curves with a mean gap of 10.5 days between the procedures, Pankaj Kandwal et al. found that with anterior release, there was an improvement in the preoperative Cobb angle of 116.6° to 74.0°. 29.4% correction, and the final postoperative Cobb angle after posterior instrumentation was 26.5° with a final 76% correction. Halotraction or cervical traction can be applied after anterior release for better correction.

However, the authors found that in a selected group of patients after careful assessment of pulmonary function and nutritional status, single-stage anterior release and posterior instrumentation can be performed, which can reduce the duration of hospital stay and postoperative recovery time.

Case Vignette 1
16/M with severe and rigid scoliosis of 95° managed with one stage T5–9 anterior discectomies and rib head excision with posterior apical and periapical Ponte osteotomies. Postoperative radiograph showing a good correction and balanced spine with posterior instrumentation performed from T3–L3 (Fig. 4).

Stand-Alone Anterior Scoliosis Correction and Instrumented Fusion

Stand-alone anterior scoliosis fusion surgery is usually planned for isolated single curves such as the Type 5C thoracolumbar/lumbar curve (left) and Type 1 main thoracic curve (right). The anterior instrumentation in such types is decided based on flexibility, the magnitude of the curve, stable vertebra, neutral vertebra, etc., and by the Hall fusion selection principle.

Hall fusion selection principle—First assess the standing PA radiograph and determine the apex of the curve (maximally away from CSVL), which can be a vertebra or disc. If AV is a vertebra, one vertebra above and below is the UIV and LIV. In the case of the disc being the apex, two vertebrae above and below the disc are included in the infusion. Then, the supine side-bending films are analyzed to assess the flexibility of the discs. For the right side, lumbar curves bending to the convexity side (right) and concavity side (left) are taken in the supine position. The first disc out of the fusion level is decided upon by the previous step; if it is mobile

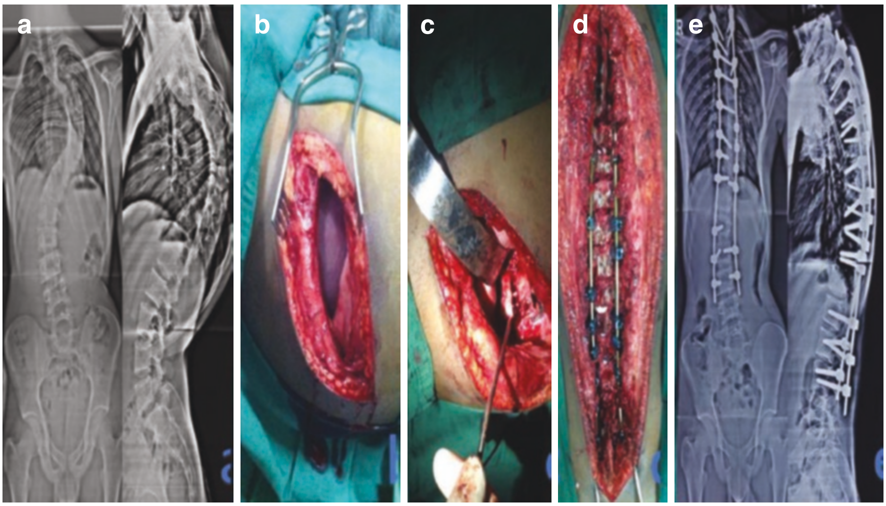

Fig. 4 Case Vignette 1. (**a**) Preoperative radiograph of severe and rigid scoliosis. (**b**) Anterior thoracotomy approach. (**c**) T5–9 anterior discectomy and rib grafting. (**d**) Posterior Ponte osteotomies and T3–L3 pedicle screw instrumentation. (**e**) Postoperative radiographs with adequate balance

on both sides in bending radiographs, then it is left unfused. To achieve truncal balance, the vertebra chosen for fusion must be horizontal and lie over the sacrum in a concavity side-bending radiograph. Some amount of L5 residual tilting can be left if an overcorrection of the curve can be achieved. The levels of fusion are planned based on the above steps, and in the case of any discrepancies in the preceding steps, a longer level of fusion is chosen [10].

In general, one can perform stand-alone anterior scoliosis fusion surgery from Cobb's upper to lower end vertebra, i.e., UIV = UEV to LIV = LEV.

Indications and Contraindications

Anterior scoliosis fusion has certain benefits over posterior fusion surgery, such as lower levels of fusion, better axial correction, and good fusion rates. The indications of anterior scoliosis surgery are in cases where the benefits are better than posterior procedures, in the following cases:

1. A single major curve in neutral film <80 and a flexible variety.
2. Thoracic hypokyphosis and significant axial rotation.
3. Immature spine prone to the crankshaft phenomenon.
4. Syndromic patients prone to pseudoarthrosis—NF, prior radiation to the spine, etc.

However, it has side effects such as pulmonary function impairment, poor cosmetic scarring, and kyphosing effects in lumbar surgery owing to the anterior approach; hence, in cases with intrathoracic adhesions, reduced pulmonary function, and intra-abdominal visceral abnormalities, this technique is contraindicated. Patients with a small vertebral size and patients with poor bone stock, such as neuromuscular scoliosis, will have less pull-out strength for instrumentation and are relative contraindications for the anterior approach. In the current scenario, the Lenke 5C type is an ideal indication for anterior scoliosis fusion surgery.

Surgical Technique

The major curve is approached from the convexity and hence its right-sided thoracotomy or left-sided thoracolumbar transdiaphragmatic retroperitoneal approach for the majority of cases. A single thoracotomy is sufficient to access seven motion levels between T4–12 levels, but one may need a double thoracotomy in cases of instrumentation extending beyond T4 and T12. After exposure, a complete discectomy was performed in the usual fashion as discussed previously.

Instrumentation

Following discectomy, the next step is the instrumentation of the vertebrae, and either a single or dual rod system can be used. In a single rod system, single fixed head vertebral body screws of 5–7 mm diameter are inserted either in the equator of each vertebra or adjacent to the endplate. The latter technique of screw insertion adjacent to the endplate has better insertional torque and pull-out strength than the other technique inserted in the equator. The use of pronged staples and a bicortical purchase by perforating the far cortex can increase the fixation strength of the screws. Proper care should be taken in screw insertion, especially in dual rod systems, to avoid violation of the spinal canal and disc spaces and appropriately sized screws to avoid far cortex screw-related adjacent structure damage. This is possible by clearly demarcating the vertebral borders, proper imaging, and palpation of the screws on the far lateral concave side. The screws are inserted from the posterior to an anterior direction parallel to the posterior vertebral border at the apical rotated vertebrae under imaging, and other screws are placed slightly anteriorly.

Rod Placement and Maneuvering

A prebent single or dual rod of size 4.5 or 5.5 is inserted into the screw heads, and the rod is rotated toward the sagittal position, which derotates the scoliosis deformity. Intervertebral grafting and cages should be strategically placed before rod insertion to achieve lordosis in the lumbar curve. Apart from the correction maneuver described above, one can use a cantilever mechanism by cantilevering the rod kept in line with a normal sagittal plane to the screw heads. Once the rod/s is/are reduced and aligned in the normal sagittal plane, with major correction of scoliotic deformity, a final correction of the residual deformity in the axial plane is performed with vertebral derotation and in the coronal plane by compression maneuver. Intraoperative neural monitoring is checked at every crucial step to check neural spinal cord integrity.

Complications

Apart from the anterior approach, related complications such as respiratory compromise, paralytic ileus, intra-abdominal visceral damage, and procedure-related specific complications do occur. They are loss of deformity correction, loss of lumbar lordosis, coronal and sagittal imbalance [11], worsening of the thoracic curve and rib hump [12].

Review of Literature

Wang et al. [13], in their cohort study of 22 young patients comparing anterior (13 cases) vs posterior fusion (9 cases) surgeries for 5C curves, concluded that anterior surgeries reduce the number of fusion segments by lowering the UIV level. The number of distal unfused segments also remained significantly higher in anterior surgeries than in posterior surgeries, even for patients with higher skeletal maturity. A similar type of result was observed by Li et al. in their patients, where anterior spinal fusion segments were 5.09 and 6.13 in posterior spinal fusion, which was statistically significant [14]. The number of lumbar vertebrae available for spinal mobility is significantly higher than that in posterior scoliosis surgeries, which could reduce early degeneration and back pain [15].

Concerns have been raised regarding the impairment of pulmonary function, and the available reports are contradictory. It is shown that violation of the chest wall by anterior thoracotomies for main thoracic curves is deleterious in a 10-year follow-up by Gilman et al. [16], whereas even though the initial reduction in the postoperative period is noted there were no harmful effects noted after double thoracotomies at 2-year follow-up by Bullman et al. [17, 18]. In thoracolumbar anterior approaches, the long-term follow-up of AIS patients operated with ASF has shown no compromise in pulmonary function as observed by Sudo et al. in 32 patients with 12–23-year follow-up [19]. Considering the amount of blood loss and surgical duration, anterior procedures have fewer transfusions and longer durations than posterior procedures [20, 21].

The clinical outcomes evaluated by SRS scores of the patients were comparable between anterior and posterior procedures in the majority of the studies [22–24].

The autocorrection concept of the compensatory curve was first introduced by Moe et al. in 1950, who advised selective fusion. There remains still a lack of data regarding the optimal approach that gives maximal correction with fewer complications. Sanders et al. found a reduction in the thoracic Cobb angle in Lenke 5c with sagittally and coronally balanced spines by an anterior approach [11, 12].

Case Vignette 2

15/F with lumbar scoliosis type 5C of the 43° curve, operated with scoliosis correction and fusion surgery using an anterior approach and a single rod system. An anterior retroperitoneal approach was used to perform discectomy, packing of interbody bone grafts, and instrumentation. The postoperative radiograph shows a good correction of the curve to 0° with a coronally and sagittal balanced spine (Fig. 5).

Anterior Vertebral Body Tethering (AVBT)–VATS Approach

The most common nonfusion technique for correcting adolescent idiopathic scoliosis is anterior spinal tethering, which leverages the Hueter-Volkmann principle to alter longitudinal bone growth [25]. Compression of convexity can restrict growth

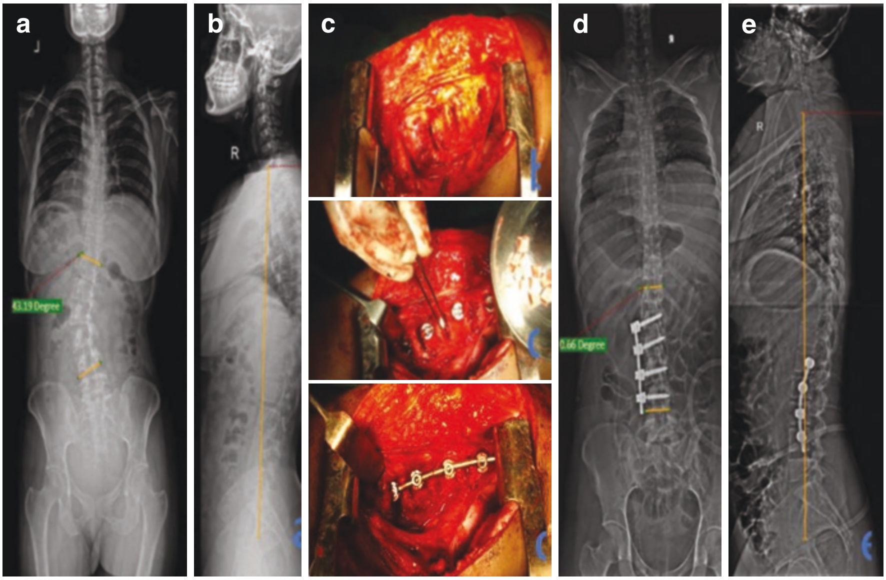

Fig. 5 Case Vignette 2 (courtesy: Dr. Vidyadhara S, Manipal Hospitals, Bangalore). (**a**) Preoperative AP & Lat radiographs. (**b**) Lumbar exposure with exposed scoliotic spine and post discectomy. (**c**) Rib graft application in intervertebral disc space between instrumented vertebrae. (**d**) Rod applied in screw tulip. (**e**) Postoperative whole spine radiograph with good correction

and allow the concave side to increase in longitudinal growth, thus reducing vertebral wedging.

Anterior vertebral body tethering (AVBT) was described by Crawford and Lenke, which allows gradual curve correction by changing the shape of the vertebra and preserves spine mobility with minimal associated morbidity. In this technique, tethering of the spine is performed by using staple and screw instrumentation with a cable connecting the screws; the cable modifies the local forces on the vertebrae and functions as an early and progressive mechanism of correction of the deformity [26].

The introduction of video-assisted thoracic surgery (VATS) has brought about a real revolution in pediatric scoliosis surgery, and the initial results of this approach are encouraging [27].

Indications and Contraindications

Idiopathic scoliosis in skeletally immature patients with the following characteristics:

1. Curves ranging between 35° and 60°.
2. At least 50% flexibility or bending to <30°.
3. Thoracic kyphosis <40°
4. Rotational parameter <20°.

Skeletal maturity is analyzed using a variety of factors, including the Risser sign ~2, Sander's score ~4, and menarche status [28]. It is contraindicated in adult patients and results in rigid scoliosis. However, currently, some surgeons are trying even in the adult mature scoliotic spine, but long-term results are not known.

Surgical Technique

The patient was positioned similarly to that previously described.

Portals: Provided through two anterior portals. First, a 2-cm incision is made anterior and slightly inferior to the scapular tip for the initial VATS working port. The latissimus dorsi is retracted posteriorly, and the serratus anterior and intercostal muscles are split. Another second 5-mm working port is placed under thoracoscopic visualization low in the chest to allow access to T12 and L1 vertebral bodies (Fig. 6b) [29].

The trocar positioning included three 5-mm ports on the anterior axillary line between the fourth and the eighth intercostal spaces. In general, these portal incisions are placed over the rib so that two to three spinal levels can be instrumented (above and below the associated rib) through each skin incision. The awl, for preparing the screw placement, tap for tapping the entire length of screw placement, and checking the integrity of walls using ball tipped probe are the usual steps of screw insertion. The screw trajectory was measured, and hydroxyapatite-coated screws with staples were inserted. Insertion of the screws must take place perpendicular to the vertebral body (Fig. 6c), and its positioning is confirmed by fluoroscopy. The polyethylene tether is inserted through the most caudal incision and placed in the tulips of the screws starting from the two most cephalic positions and locked with a screw set (Fig. 6d). The tether is put under traction and progressively positioned through the more distal screws before completing the tethering of the entire spinal curve. The tether is cut on either side, a chest tube for drainage is placed through the lower thoracoscopic portal, and the collapsed lung is ventilated under direct visualization. A postoperative chest radiograph was obtained for monitoring pneumothorax [30].

At the lumbar level, the L2–L4 levels were accessed through an oblique 4–6 cm incision over the lateral flank. Dissection is carried through the external oblique, internal oblique, and transversalis abdominis muscles to the retroperitoneum. The psoas muscle is identified, and the peritoneum is bluntly dissected anteriorly to reveal the psoas muscle from the level of the diaphragm to the desired level. Sequential dilators to identify the lumbar plexus and progressively distend the psoas musculature away from the intended screw trajectories may also be applied. Multiple long narrow retractors are needed to provide adequate visualization again to ensure that the starting point of the screw is clear from the lumbosacral nerves. An awl is used to prepare the screw entry site, and the full trajectory is preliminarily tapped. A 6-mm hydroxyapatite-coated titanium screw was then placed. The process is repeated for the remaining lumbar vertebra. Typically, the L2 and L3 screws can be placed through the same incision. A second incision and retroperitoneal approach

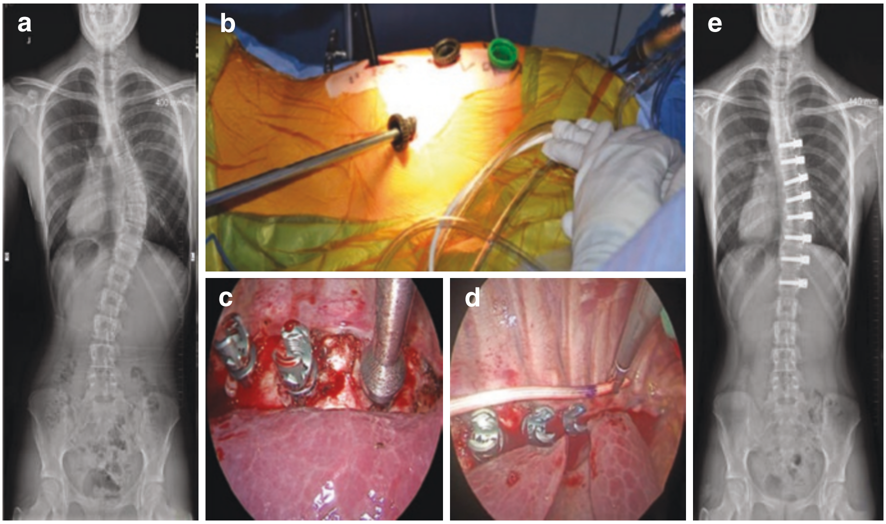

Fig. 6 Case Vignette 3 (courtesy: Dr. Amer F Samdani & Joshua M Phys, Shrines Children Hospital). (**a**) Preoperative radiograph showing thoracic scoliosis. (**b**) VATS portals. (**c**) Insertion of hydroxyapatite screws perpendicular to the vertebral body. (**d**) Tether inserted through the caudal incision into tulips. (**e**) Postoperative radiograph with good correction of scoliosis

are sometimes required for the L4 screw. Once all the screws were placed and neuromonitoring checks were performed, tensioning of the distal instrumented levels was performed first. One end of the cord is cut since tensioning is performed from the caudad to the cephalad. The lumbar spine is more flexible than the thoracic spine, and over-tensioning should be avoided. Sequential tensioning is then carried out as indicated based on the curve magnitude, flexibility, and growth remaining [31].

In the case of thoracolumbar curves, after the thoracic and lumbar screws were placed, the next step was to pass the cord from the retroperitoneal space into the chest. A retractor was placed superiorly in the abdominal wound to expose the undersurface of the diaphragm. Typically, placement of the L1 screw results in a small window in the diaphragm. The thoracoscope is placed in the chest for visualization, and then the L1 screw is manually palpated from the retroperitoneal incision and is usually readily felt. Then, a large, blunt hemostat can be used to pass the cord from the retroperitoneal incision safely up into the chest under thoracoscopic visualization. Tensioning is then carried out through the thoracoscopic approach according to the preoperative plan. When curvature and tension are deemed appropriate, set screws are finally tightened, and the excess proximal cord is trimmed. Before closure, the opening in the diaphragm was closed thoracoscopically, a chest drain was placed through the lower thoracoscopic portal, and the collapsed lung was ventilated under direct visualization. The retroperitoneal exposure and thoracic portals are closed in layers. A postoperative chest radiograph was obtained for monitoring pneumothorax. The procedure duration was 3–4 h [32].

Pitfalls, Tips, and Tricks

Trocar positioning is the key to correctly placing the screws in the vertebral bodies. Intraoperative fluoroscopy helps guide the surgeon for correct screw insertion. The azygos vein has the risk of bleeding and needs special attention and is better done using delicate and precise bipolar forceps or a thin instrument combined with a bipolar coagulation device. The parietal pleura must be incised carefully along the marginal spine, and good exposure of the veins is important to avoid vessel damage. Small branches of the paravertebral veins need accurate hemostasis.

Damage to the phrenic nerve can be avoided using proper exposure and visualization of its course.

The thoracic duct's possible anatomic variations should be considered, and injuries should be avoided.

A correct interaction between orthopedic spine surgeons, expert radiology staff, thoracic/VATS-trained access surgeons, pediatric anesthetists, neurologists, experts, and physiotherapists is needed for the successful outcome of the surgery [33].

Complications

Overcorrection or undercorrection of the spinal curve, progression of scoliosis despite tethering, screw migration, tether breakage, neurologic injury, and vascular injury to the great vessels are certain complications. Regarding undercorrection, overcorrection, or curve progression, treatment options include revision tether surgery or posterior spinal fusion. The pulmonary consequences (pneumothorax, hemothorax, chylothorax, chest wall pain) of revision tether surgery are unknown, and the presence of scar tissue in the thoracic cavity and retroperitoneum can present significant challenges. Others include dural leakage and injury to the ureters, viscera, visceral injury, and lumbosacral plexuses [34].

Review of Literature

Vertebral body tethering (VBT) is an alternative technique to bracing for pediatric patients with a moderate degree of scoliosis. Fusion can be avoided in >70% of thoracic curves between 25° and 35° and in >80% of lumbar curves between 25° and 45° [35]. In 2010, Cuddihy et al. had good results in their study comparing VBS to bracing for patients with moderate idiopathic scoliosis [36]. Newton et al. in their study with a mean 2.5-year follow-up of 17 skeletally immature cases, noted progressive correction over the first 2 years, from a mean of 52° preoperatively to 31° immediately postoperatively and 24° after 2 years [37].

The VBT technique as a result of the utilization of growth modulation was able to yield a significantly superior lumbar range of motion, lumbar anterior and lateral flexibility, trunk flexor-extensor endurance, and trunk motor strength compared to patients who underwent fusion in immature patients with AIS. The SRS-22 and SF-36 scores were better with VBT than with fusion [38].

Out of all cosmetic concerns, rib hump improvement is a key expectation for parents and adolescents considering surgery. There are studies that reported to have 30% to 45% rib hump correction. These corrections are in keeping with finite element analyses but less than available axial plane data following AVBT. However, comparative data highlight that rib hump resolution is better with fusion surgery [39].

5 Conclusion

Anterior release procedures with posterior instrumentation are best suited for their use in severe and rigid scoliotic curves, with compensatory structural curves. Isolated lumbar 5C-type curves are best treated with stand-alone anterior scoliosis correction and fusion surgeries because of the shorter segments of fusion. Anterior vertebral body tethering, a growth modulation technique, avoids fusion and its related consequences in limited cases; however, long-term studies are needed to validate the true benefit of this technique. There has been a definite advantage of anterior over posterior surgeries in the form of better correction, with fewer levels of surgeries, less blood loss, and posterior muscle sparing. A major drawback of anterior surgery is chest wall violation-related side effects, which are avoided by thoracoscopy, but it necessitates a longer learning curve. However, one must decide on the approach based on the potential benefits over the disadvantages in choosing the approach.

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