Technical Note

A Thoracoscopic Technique Used in Anterior Vertebral Tethering for Adolescent Idiopathic Scoliosis

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Abstract: Anterior vertebral tethering (AVT) is a relatively recent alternative to posterior spinal fusion for progressive curves in growing patients with idiopathic scoliosis. AVT uses a thoracoscopic approach to minimize trauma to the thoracic wall and chest cavity. There are limited technical descriptions of this method. Patients benefit from proficiency and reproducibility to allow for appropriate spinal curve correction over time. This Technical Note outlines the steps of the thoracoscopic approach to AVT and reviews the current indications for AVT over posterior spinal fusion, as well as the most recently published clinical outcomes of this procedure.

For patients with adolescent idiopathic scoliosis who have curves that progress to greater than 45°, posterior spinal fusion (PSF) has long been considered the gold standard for treatment. However, PSF permanently eliminates growth and motion of the fused spinal segments. Alternative treatment options have been investigated, aimed at correcting the deformity while preserving spinal motion.[1,2] One recently developed fusion-less alternative to PSF is anterior vertebral tethering (AVT), in which anchors are placed in each vertebral body within the deformity and connected by a tether cord. A polyethylene terephthalate tether is then tensioned on the convex surface of the curve, providing partial curve correction. Tensioning provides unilateral compression that allows for differential growth according to the Hueter-Volkmann principle. The intrinsic growth remaining in the adolescent spine allows for continued deformity correction and maintains these changes over time while preserving intervertebral disk health.[3-5]

Three approaches are used to place the anchors and tether depending on curve pattern and location including thoracoscopic, mini-open, and hybrid techniques. The thoracoscopic approach was developed to minimize injury to the chest wall and thoracic cavity during surgery and improve postoperative outcomes.[6] Thoracoscopic anterior spinal instrumentation has been described for arthrodesis, but there are few descriptions of this technique for the AVT procedure.[7] This article describes the minimally invasive thoracoscopic approach for AVT surgery and reviews the indications and clinical outcomes of this motion-sparing, guided growth technique for spinal deformity correction.

Surgical Technique for Thoracoscopic Approach

Patient Positioning

The surgical technique is shown in Video 1. The patient is initially placed in the supine position on the operating table with a general anesthetic. Intubation is performed with a double-lumen endotracheal tube, with proper positioning of the tube verified by

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bronchoscopy. Single-lung ventilation allows the convex lung to collapse for safe access to the spine. The patient is then transitioned to the lateral decubitus position, with the convex side of the curve facing upward (Fig 1). All bony prominences are padded, and the head and neck are stabilized in a neutral position. The hips and knees are also flexed and padded to diminish tension on the lower-extremity nerve roots. The thorax and abdomen from the umbilicus anteriorly to the spine posteriorly are prepared and draped in the standard sterile manner. Baseline motor and somatosensory evoked potentials are obtained (Fig 2).

Portal Placement

A lateral spine image is obtained using a large image intensifier (Philips North America, Cambridge, MA), and the trajectory of the thoracic and lumbar spine is marked on the overlying skin. The intensifier is moved to the posterior-anterior projection to identify the end vertebrae to be instrumented, and the parallel

Fig 1. View of patient with head pointing toward top of image. After double-lumen endotracheal intubation in the supine position, the patient is placed in the lateral decubitus position. The convex side of the spinal curve is positioned upward (right side in this patient). An axillary roll is used. Extensive padding is placed at all bony prominences, leaving the common peroneal nerve free of pressure in the region of the fibular head. The hips and knees are slightly flexed to avoid undue tension on the nerve roots of the lower extremities, and pillows are placed between the legs. The head and neck are maintained in a neutral position, and the patient is taped to the bed to ensure stability.

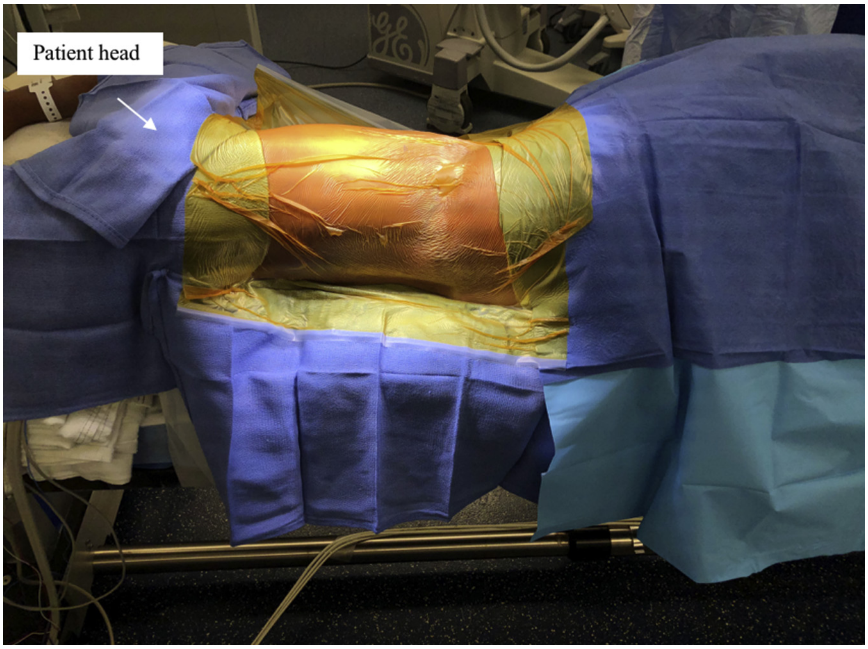

Fig 2. View of patient with head to left. After positioning, the patient's thorax and abdomen are prepared and draped in the standard sterile manner. In this view, the patient's right side is facing upward prior to final drape placement, in preparation for tethering of the T5 to T11 spinal levels.

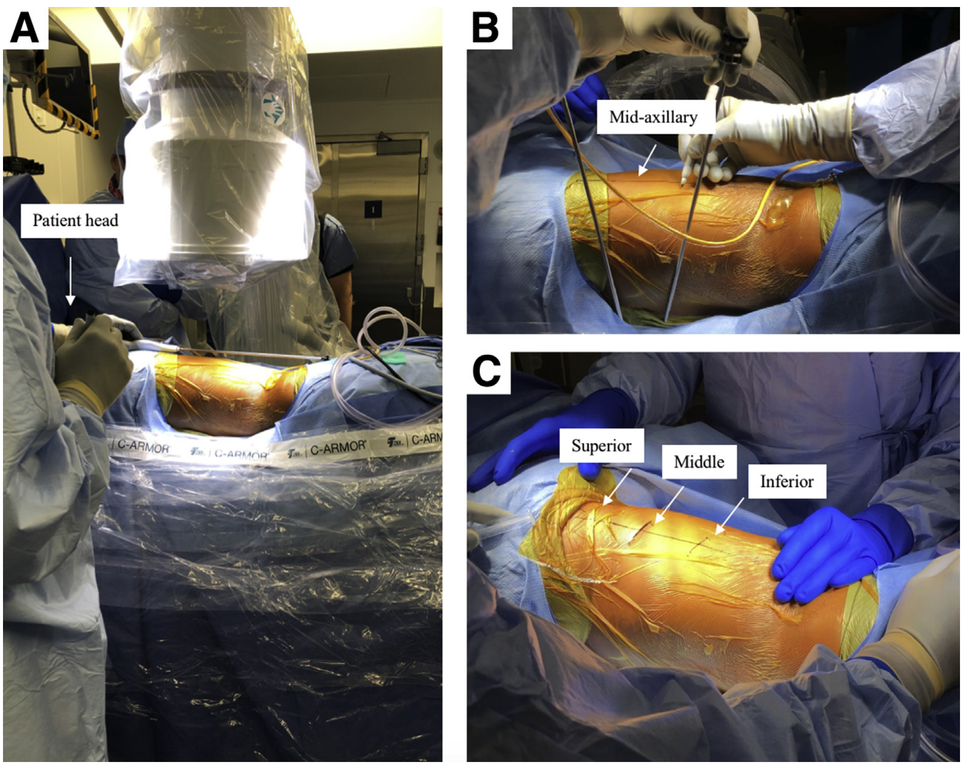

Fig 3. Views of patient with head to left. (A) An image intensifier in the lateral projection is used to identify the course of the vertebral bodies, which is usually in the midaxillary line. (B) The image intensifier is moved to the posterior-anterior projection to identify the spinal vertebral levels. (C) The best 3 intercostal spaces to provide parallel access to the levels to be tethered are marked across the midaxillary line as the superior, middle, and inferior portal incisions.

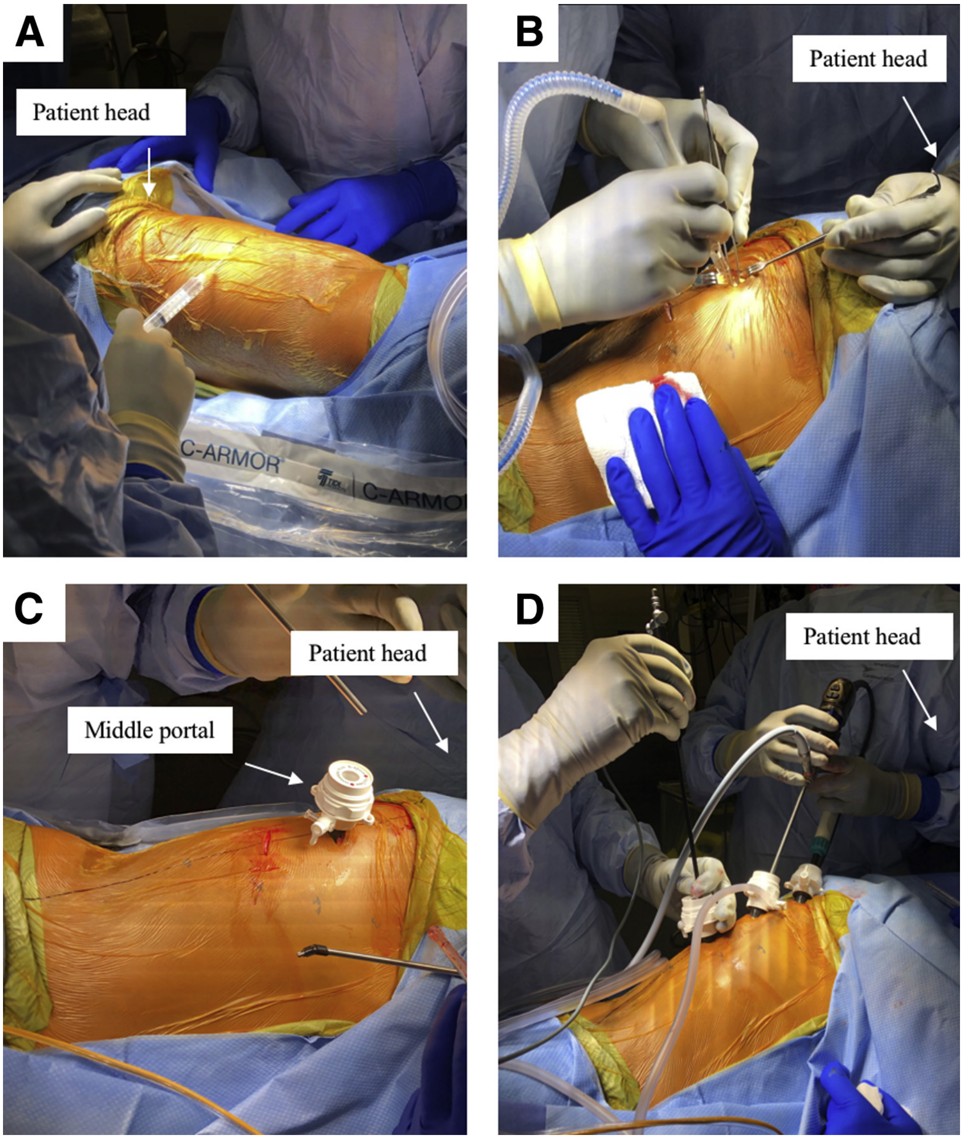

Fig 4. Views of patient with head to left (A) and to right (B-D) directions. All 3 portal incision markings are infiltrated with 0.25% bupivacaine with epinephrine. (A) The middle portal incision is created first. Electrocautery is used to dissect the intercostal muscles, and the pleura is bluntly opened, coming over the top of the rib to avoid the intercostal bundle (B), after which a 12-mm portal is placed (C). (D) The thoracoscope is then inserted to assess lung deflation and to aid in creation of the remaining 2 portals.

trajectories are marked on the skin (Fig 3). The 3 intercostal spaces that are determined to provide the best access to these levels are identified, and oblique 2.5-cm incisions along the midaxillary line are outlined. After injection with 0.25% bupivacaine with epinephrine, the middle incision is made first, paralleling the intercostal space (Fig 4A). Electrocautery (Bovie Medical, Melville, NY) is used to aid dissection of the intercostal muscles down to the rib. The pleura is carefully opened, coming over the superior aspect of the rib to avoid the intercostal neurovascular bundle, and a 12-mm thoracoscopic portal is placed (Fig 4 B and C). The chest cavity is insufflated with carbon dioxide to aid in lung deflation. A 30°, 5-mm thoracoscope (Karl Storz, Tuttlingen, Germany) is then placed through the portal to assess the success of lung deflation, as well as spine exposure, and to assist in placement of the subsequent portals (Fig 4D). Alternatively, a 10-cm flank incision can be used for retroperitoneal access for thoracolumbar and lumbar curves.

Anchor and Tether Arrangement

Under thoracoscopic visualization, the spine is marked and a shoot-through anterior-posterior image

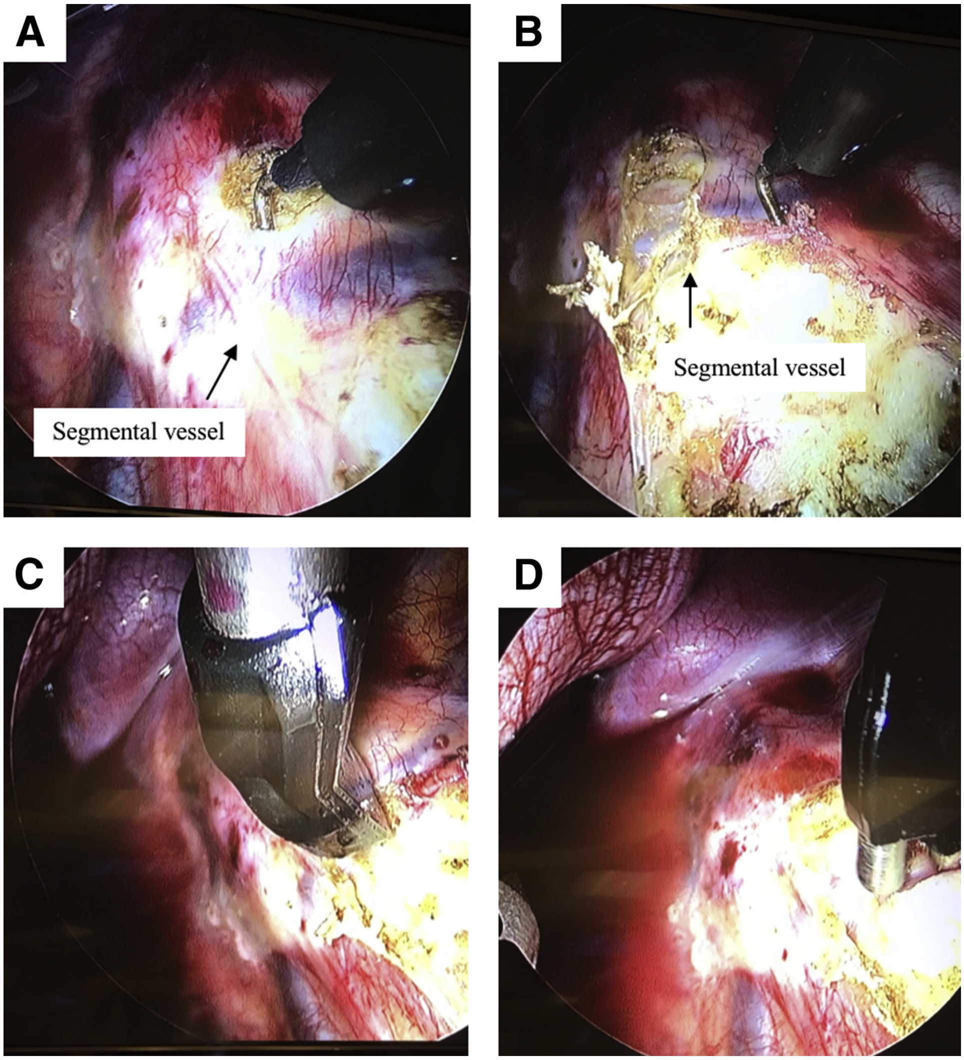

Fig 5. Views of spine inside chest from superior portal, with patient's head directed inferiorly and front of body to left. A hooked endoscopic electrocautery device is used to open the spinal pleura (A), at which point the segmental vessels of each vertebra are exposed (B). An Aquamantys wand is used to coagulate the segmental vessels (C), and electrocautery is used to divide the segmental vessels and expose the lateral vertebral body (D), prior to placement of anchors.

is obtained to confirm the spinal level. A hooked electrocautery device (Bovie Medical) is used to open the spinal pleura, minimally exposing the lateral vertebral body without violating the disk spaces, and a thoracoscopic bipolar sealer (Aquamantys; Medtronic, Minneapolis, MN) is used to coagulate and divide the segmental vessels (Fig 5) over the mid portion of the vertebral body. Beginning at the caudal-most spinal level to be tethered, biplanar fluoroscopy is used to identify the midpoint of the vertebral body on the convex side and a straight awl (Zimmer Biomet, Warsaw, IN) is used to create a starting hole in the mid portion of the vertebral body. A blunt, straight pedicle probe (Zimmer Biomet) is advanced across the vertebral body under biplanar fluoroscopic guidance and passed through the contralateral cortex (Fig 6A). The probe is removed, the proximal cortex is tapped, and a 6.5-mm-diameter tether anchor (Zimmer Biomet) of appropriate length is placed in a bicortical manner, allowing for no more than 2 to 3 mm of tip prominence (Fig 6 B-E). A motor evoked potential is then obtained. This procedure is repeated for each indicated vertebral level.

Once all anchors are safely placed, the tether (Zimmer Biomet) is introduced into the thoracic cavity through the most caudal portal and placed within the cephalad anchor, leaving approximately 2 cm of excess cephalad (Fig 7A). A set screw is then placed within the anchor and tightened to the manufacturer's suggested torque (Fig 7 B and C). The tether is fed through the next

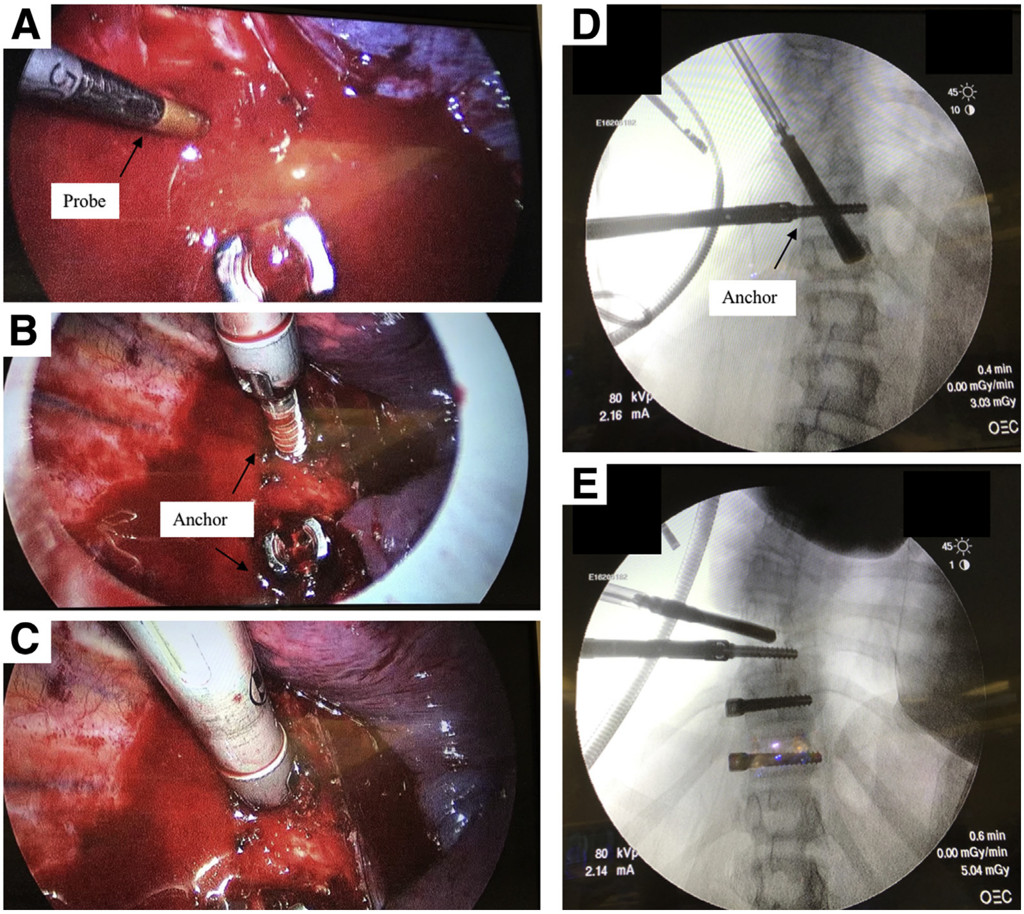

Fig 6. (A-C) Views of right side of thoracic spine from inferior portal during anchor placement, with patient's head pointing toward top of image and front of body to right. For each anchor placement, a pedicle probe is used to create an initial trajectory transversely across the vertebral body. Length measurements are determined from radiographs preoperatively and confirmed by markings (A) on the probe. The probe is removed, the proximal cortex is tapped, and an anchor tether is advanced (B) until the tip of the anchor crosses the far cortex and 2 to 3 mm protrudes from the distal cortex (C). (D, E) Fluoroscopic views of spine during anchor placement, with patient's head directed toward top of image and front of body to left.

caudal anchor, the counter-torque tower and tensioning device (Zimmer Biomet) are secured at this level, and the set screw is loosely applied (Fig 7D). The tether is tensioned between these spinal levels to an appropriate amount, with additional downward pressure on the tether anchor applied through the tower by the assistant, and the set screw is torqued (Fig 7E). This procedure is repeated for each anchor, with the highest tether tension applied at the curvature apex and less progressing toward the construct ends. When the construct is complete, excess tether is cut, leaving approximately 2 cm of excess, and a radiograph is obtained to determine immediate scoliotic curvature correction (Figs 7F and 8). The chest is irrigated, and the thoracoscopic portals are closed in layers (No. 2-0 Vicryl [Ethicon, Somerville, NJ] for deep layers and No. 4-0 Monocryl [Ethicon] in the skin). Prior to closure of the most inferior portal, a chest tube is temporarily inserted and the lung is expanded with recruitment maneuvers performed by the anesthetist; once full expansion is achieved, the chest tube is removed. With the patient in the lateral position prior to awakening, a lumbar puncture can be performed and 300 to 400 μg of preservative-free morphine is added to the cerebrospinal fluid for postoperative pain relief. Rib blocks with 0.25% bupivacaine with epinephrine are also performed.

Postoperative Protocol

After surgery, patients undergo pulmonary and pain monitoring, with posterior-anterior and lateral chest radiographs taken prior to discharge. The urinary catheter is typically removed on the morning of postoperative day 1, and patients can begin working with physical therapists. Patients are typically discharged on postoperative day 3. Healthy patients are expected to

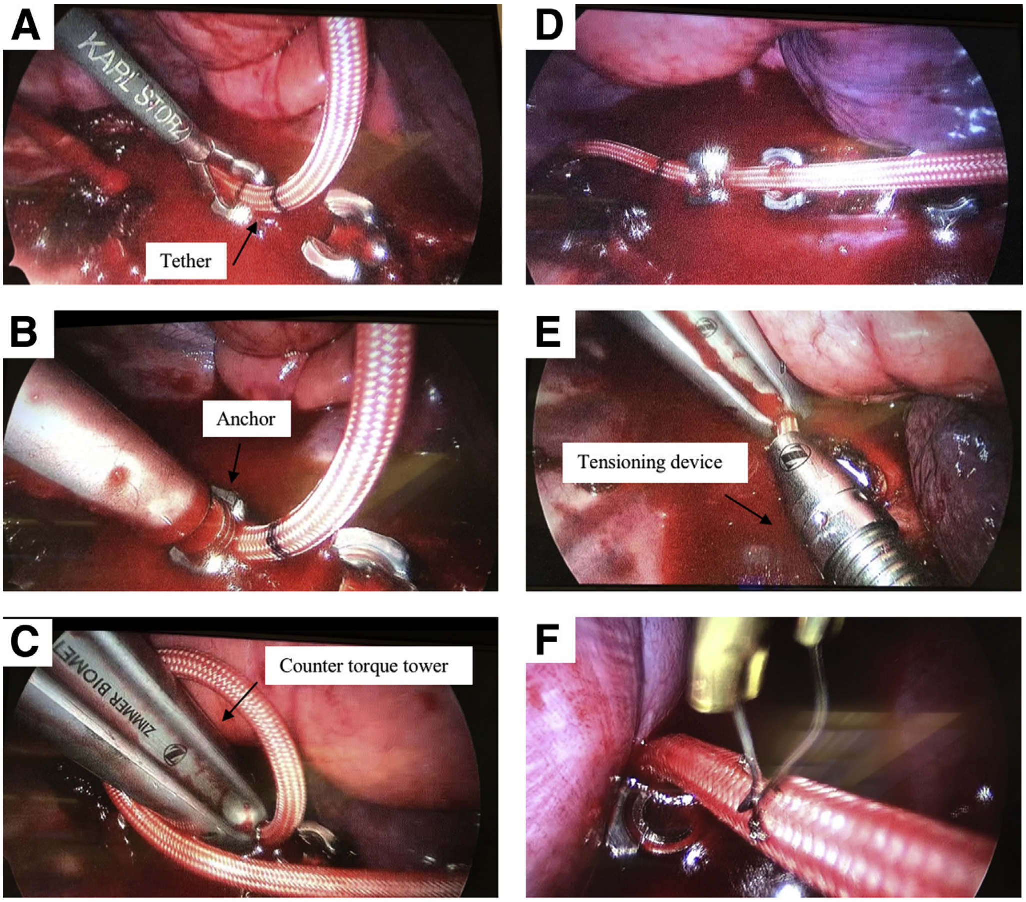

Fig 7. Views of right side of thoracic spine from middle portal during tether placement, tensioning, and cutting of excess tether. The patient's head is directed superiorly and to the left (A-C, E), to the left (D), and inferiorly (F), with the front of the torso superiorly and to the right (A-C, E), superiorly (D), and to the left (F). A marking is made on the tether 2 and 3 cm from its cut end. (A) This end is fed through the most cephalad anchor until the 2-cm mark is roughly even with the cephalad part of the anchor and the 3-cm line is at the caudal aspect of the anchor. A set screw is placed within the anchor containing the tether (B), and a counter-torque tower is placed over this construct to tighten the set screw to the appropriate torque (C). (D) The tether is then fed through the next caudal anchor. (E) A tensioning device is used along with the set screw and counter-torque complex to tension the tether between the 2 vertebral bodies, and the set screw is torqued. This is repeated at each level in a cephalad-to-caudal direction. (F) After the final set screw is torqued, the excess tether is cut 2 cm below the most caudal anchor using a handheld battery cautery.

return to independent baseline activity in 12 weeks. Patients return to the office for evaluation and radiographs at 6 weeks, 12 weeks, and 6 months postoperatively, followed by every 6 months until skeletal maturity is reached.

Discussion

AVT is indicated in growing patients with closed triradiate cartilage who have progressive idiopathic curves that have not responded to bracing. Recent data have suggested that even young, skeletally mature patients with flexible curves can benefit from AVT (Table 1). Growing patients with idiopathic curves greater than 25° generally undergo bracing and are observed for progression. If a curve fails to respond to bracing and progresses to greater than 40°, AVT may be an option if there is enough spinal growth remaining to take advantage of guided growth. The advantages of AVT over PSF include a shorter operative time, less soft-tissue trauma, less blood loss, less pain, and a shorter

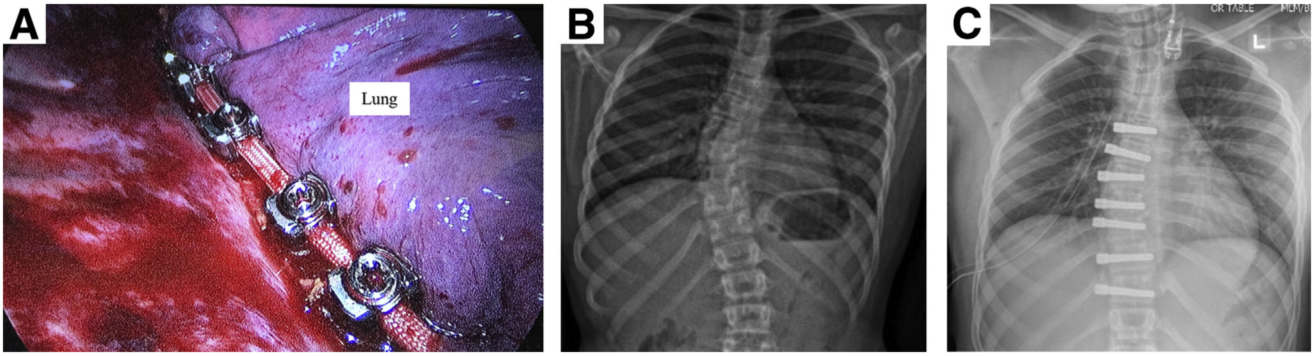

Fig 8. Thoracoscopic view illustrating completed tether and anchor arrangement on right side of spine (A), with patient head directed superiorly and to left and with front of body superiorly and to right, and posterior-anterior radiographs of thoracic scoliotic curve preoperatively (B) and immediately postoperatively (C) after anterior vertebral tethering, with patient head directed superiorly and with right side of spine to left. Patients have some initial curve correction from tether placement, with additional correction with growth. (L, left.)

hospital stay. Longer-term advantages include the potential to correct curves while preserving spinal motion and maintaining the health of adjacent intervertebral disks. Disadvantages of AVT include the current lack of long-term data on the clinical outcomes of the procedure, the risk of overcorrection of the spinal deformity, and complications, which may require additional surgery. Procedural complications can be categorized as approach related or implant related (Table 2). Those due to approach include pneumonia, pneumothorax, and hemothorax, which can occur but are easily treated, as well as injury to surrounding organs and neuronal and/or vascular structures, which can be diminished by a consistent and experienced surgical team. Implant complications include tether rupture, which is far more common than anchor malposition or loosening. The occurrence of tether rupture, which is usually asymptomatic and does not require revision, can be reduced by techniques that protect the tether during implantation and reduce stress on it over time.

Table 1. Indications, Advantages, and Disadvantages of Anterior Vertebral Tethering

Ideal indications
Diagnosis of idiopathic scoliosis
Progressive curve between 40° and 72°
Spinal growth remaining
Advantages
Preservation of spinal mobility
Shorter hospital stay
Less blood loss
Less postoperative pain
Maintained intervertebral disk health
Disadvantages
Complications (approach related and implant related)
Potential for overcorrection
No long-term clinical outcome data

Because this technique is relatively recent, there are few published studies on long-term clinical outcomes. Braun,[8] in a 2014 preliminary study with 5 AVT patients, reported an average thoracic correction from 34.5° to 31.5° postoperatively with variable curve control at 1 to 2 years. Samdani et al.,[9,10] in a study of 32 patients, similarly showed good thoracic curve correction (average of 42.8° to 21.0° postoperatively, improving to 17.9° at 12 months) but with an 18% rate of revision for overcorrection at 2 years. More recently, Newton et al.[11] published a study on their patient cohort with a 2- to 5-year follow-up and reported average thoracic curve correction from 52° to 31° immediately postoperatively and 17° at 18 months. In a 2020 study with a more skeletally mature patient cohort, Hoernschemeyer et al.[12] reported an average main thoracic curve correction from 50° to 21° postoperatively and 13° at 2 years, with 93% of patients avoiding PSF at latest follow-up. Although more studies will be needed to further characterize the outcomes and complications of AVT, this thoracoscopic approach is a reproducible and effective treatment that takes advantage of continued spinal growth in pediatric patients with adolescent idiopathic scoliosis, who would otherwise require spinal arthrodesis.

Table 2. Complications of Anterior Vertebral Tethering

Approach related
Pneumonia, pneumothorax, or hemothorax
Injury to surrounding structures (vessels [aorta, vena cava, or azygous vein]; organs [heart, lung, liver, kidney, spleen, or bowel]; and/or neurologic [spinal cord, roots, or sympathetic nervous system])
Implant related
Tether rupture
Anchor malposition
Anchor loosening

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