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Thoracoscopy for Correction of Adult Thoracic Scoliosis

George D. Picetti, III, MD[a,b,*], Dachling Pang, MD, FRCS(C)[c]

[a]Sutter Neuroscience Medical Group, 2800 L Street, Suite 500, Sacremento, CA 95816, USA
[b]Department of Orthopedics, University of California, San Francisco, San Francisco, CA, USA
[c]Department of Paediatric Neurosurgery, University of California, Davis, Mosswood Building, 285 W MacArthur Boulevard, Oakland, CA 94611, USA

Advances in surgical techniques have allowed the spinal column to be addressed by posterior, lateral, and anterior approaches. Minimally invasive techniques have permitted access to the anterior spinal column without the surgical morbidity of a conventional thoracotomy while realizing results comparable to those of an open procedure. Surgical approaches may change, but the technical procedure and operative goals remain the same.

The thorascopic treatment of lung diseases has been performed since the early 1900s, starting with the work of Jacobaeus [1]. The modern era of laparoscopic surgery began in the 1980s when Semm performed the first appendectomy. Laparoscopic surgery then rapidly took off after Mouret performed the first laparoscopic cholecystectomy in France [2]. Regan began his work on the thorascopic treatment of spinal disease in the early 1990s, which he presented in Dublin, Ireland [3]. Rosenthal and colleagues [4] were the first to publish the technique of thoracic discectomy in 1994. Other papers followed with expanded indications for the thorascopic correction of spinal deformity, including Picetti's [5].

After having gained substantial experience in thoracoscopic anterior release and fusion for scoliosis, kyphosis, hemiepiphysiodesis, and hemivertebrectomy we embarked on the development of a technique for endoscopic instrumentation, correction, and fusion of primary thoracic curves. We and others have shown that the thoracoscopic technique generally gives better visualization, improves access to the extremities of the curve, decreases blood loss and operating time, allows a shorter hospital stay and faster return to school and baseline activities, and lessens overall costs compared with open surgery. Our goal is to develop a safer and more effective endoscopic procedure than open thoracotomy while maintaining comparable or better results in restoring spinal alignment and balance in all planes as well as in achieving axial derotation.

In October 1996, we performed our first entirely endoscopic correction and fusion for thoracic scoliosis. The first few cases were done with rudimentary implants and instrumentation, and our initial results were reported at the Scoliosis Research Society in 1997 [6]. As we gained experience with the surgical technique and made modifications in the instrumentation, our results were better and our operating time had decreased significantly [7]. To date, our operating time is less than 3 hours, and our Cobb correction is 67.2%. Patients are back to work in 4 to 8 weeks [8].

Patient selection

The endoscopic technique is best indicated for single overhang primary thoracic scoliosis with a Lenke type IA or IB curve. Scoliosis with this curve pattern can be safely addressed as an isolated fusion without the risk of spinal imbalance [9]. If the patient is kyphotic as well,

* Corresponding author.
E-mail address: gdpicettiIII@rcsis.com (G.D. Picetti).

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however, this technique should not be used, because although anterior growth of the vertebral column ceases with removal of the anterior growth plates during discectomy and fusion, posterior growth continues, which aggravates the existing kyphosis. This technique is also contraindicated for double-major curves, and it should not be attempted on patients who are not able to tolerate single-lung ventilation.

Operative technique

Preoperative planning

Patients are selected based on progressive scoliosis and curve type. All curves are Lenke type 1A or 1B [9]. Clinical evaluations of pelvic obliquity, waist crease, shoulder height difference, degree of rotation, flexibility, and sagittal balance are noted and documented. Anomalies are excluded. Complete histories and physical examinations, 36-inch posteroanterior (PA) and lateral radiographs, and PA side-bending films are obtained. Cobb angles are marked in the standard fashion.

Patient positioning and portal placement

General anesthesia is administered through a double-lumen endotracheal tube. The patient is placed in the direct lateral decubitus position, with the arms forward and elevated at 90° and the elbows flexed at 90°. Hips and shoulders are taped to the operating table, which helps to maintain the patient in optimal position throughout the procedure.

The C-arm is used to mark the spinal levels and portal sites. Designation of portal site is key, because properly placed portals enable the surgeon to command the full extent of the spinal segments to be instrumented (Fig. 1).

Two endoscopic monitors are used: one monitor facing the patient and a second to the back of the patient. The lead surgeon stands at the

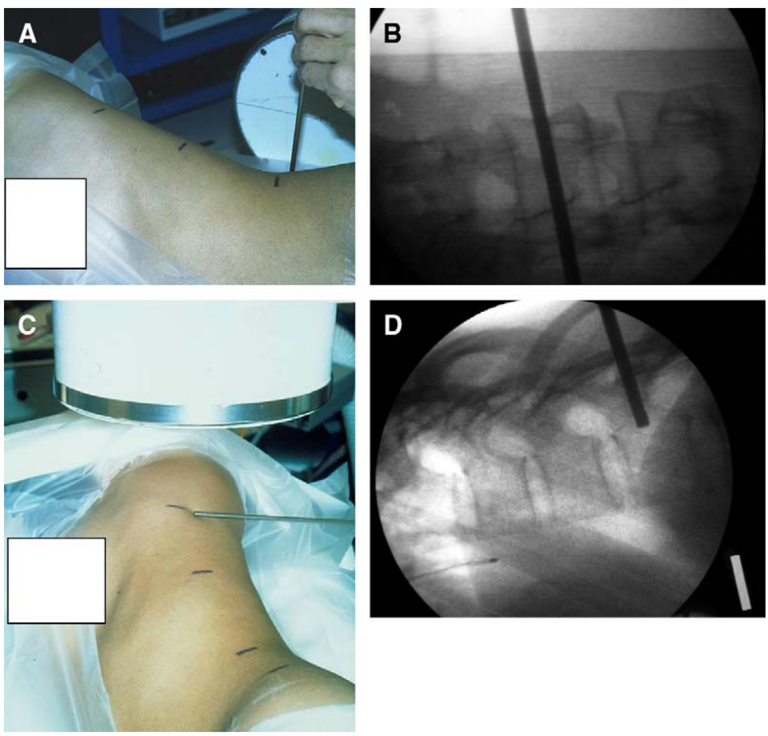

Fig. 1. (*A*) C-arm is placed in the posteroanterior (PA) plane at the distal level to be instrumented with a rod as a marker. A skin marker is used to mark the levels to be instrumented. (*B*) PA C-arm image of the rod marker parallel to the end plates of the distal level. (*C*) C-arm in position in the lateral plane uses the rod marker to determine the portal location. (*D*) Lateral C-arm image demonstrates the rod marker at the level of the rib head; the portal is to be made just anterior to this mark.

patient's back. This encourages all movements involving instruments to be directed away from the spinal cord. In addition, by standing behind the patient, the lead surgeon is orientated in the same direction as the endoscopic view and avoids having to navigate the external landmarks of the ribs and spine to a mirror image on the screen.

The C-arm is used to confirm a strict lateral decubitus position with the concave side of the curve down. This orientation gives the least distorted view of the anteroposterior (AP) and lateral trajectories of the guidewires and screws. The position is rechecked just before placement of the guidewire.

After lung deflation, the first portal is usually placed in the sixth or seventh intercostal space in line with the spine and adjusted according to the amount of spinal rotation. Choosing this level for the first portal avoids injury to the diaphragm, which is normally more caudal. Digital inspection of the portal is made to ensure that the lung is adequately deflated and no adhesion exists. The endoscope is then inserted into the chest, and additional portals are placed under direct visualization. Skin incisions for the portals are usually made directly over the ribs, two intercostal spaces apart. Two portals, one above and one below the rib at each level, can thus be made through a single skin incision. Three to four incisions are used, depending on the number of spinal levels to be instrumented. The portals are 10.5 to 11.0 mm in size.

Exposure and discectomy

The pleura is incised longitudinally along the entire length of the spine to be instrumented. The segmental vessels are grasped at the midvertebral body level and electrocoagulated. The pleura is dissected off the vertebral bodies and intervertebral discs to expose the area between the rib heads and the ipsilateral aspect of the anterior longitudinal ligament (Fig. 2).

Next, the electrocautery is used to incise the annulus of the disc and the periosteum before the latter is dissected off the adjacent vertebral bodies. After removal of the annulus and the near portion of the disc, the Kerrison rongeur is used to widen the disc space for better access by clipping off the edges of the cartilaginous end plates. Further debulking of the disc can be achieved with the endoscopic shaver, and the discectomy is completed with judicious use of the angled curettes scraping from the contralateral corners all the way back toward the part just behind the rib head. Once the disc is completely removed, the anterior longitudinal ligament is thinned from within the disc space with a pituitary rongeur to a flexible membrane remnant that is no longer restrictive but still able to contain the bone grafts. The disc space is then inspected with the endoscope (Fig. 3), and the endoscopic shaver is inserted into the disc space while a radiograph is obtained to confirm the level and to verify the completeness of the discectomy (Fig. 4). The end plates are then abraded to a bleeding surface with the rasp, and the disc space is packed with hemostatic Surgicel.

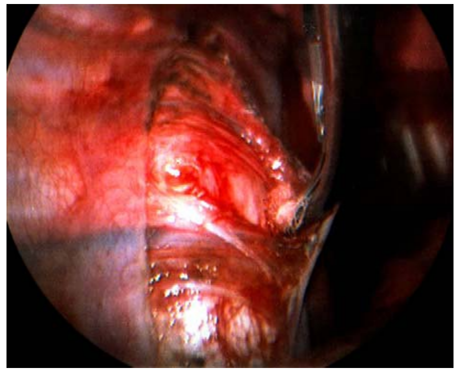

Fig. 2. Intraoperative view through the endoscope. The pleura has been incised along the midline of the vertebral bodies and is reflected off the anterior longitudinal ligament.

Graft harvest

The portals are removed after completion of the discectomy. Next, the rib is subperiosteally

Fig. 3. Intraoperative view though the endoscope of a discectomy. The cartilage has been removed from the end plates, and the anterior longitudinal ligament has been thinned from inside the disc space.

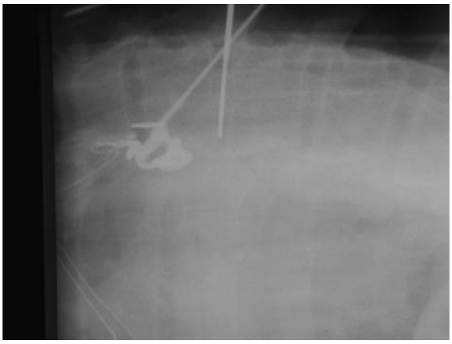

Fig. 4. Intraoperative localization radiograph with the shaver in the disc space. The shaver serves two purposes: to ensure the correct level of the discectomy and to ensure the completeness of the discectomy. The shaver is placed across the disc to the opposite annulus, confirming that the disc has been removed to the opposite side.

dissected as far posteriorly as the portal incision allows. The endoscopic rib cutter is used to make two partial incisions across the superior aspect of the rib so that an 8- to 10-cm long half-thickness graft can be harvested using an osteotome. The number of donor sites depends on the amount of morcellated graft needed to fill all the disc spaces. This half-thickness graft technique preserves the regenerative periosteum as well as the integrity of the rib cage frame, although not endangering the intercostal nerve, and thus minimizes postoperative pain. Graft harvesting is typically performed after the discectomy to avoid fracture of the weakened rib cage by the repetitive levering strain of the discectomy instruments if the sequence were reversed.

Screw placement

The Kirschner wire (K-wire) guide is situated on the center of the vertebral body just anterior to the rib head. The angle of incline of the guide in the lateral plane is first referenced on fluoroscopy to the chest wall and rotation (Fig. 5) to ensure a slight posterior-to-anterior trajectory for the K-wire away from the spinal canal. Once the guide is correctly aligned, the K-wire is inserted into the appropriate cannula; under fluoroscopic control, it is drilled into the vertebral body parallel to the end plates until its tip touches the opposite cortex. The final position of the K-wire is again confirmed with the C-arm.

The length of K-wire within the vertebral body is determined by a scale on the upper section of the K-wire at the top of the guide. After removal of the guide, the cannulated awl (with or without a staple) is inserted over the K-wire and worked into the vertebral body as the K-wire is held in place. Next, the awl is replaced by the cannulated tap to tap the near cortex of the vertebral body. An appropriately sized screw is now placed over the K-wire and advanced while the K-wire is again firmly grasped to prevent it from being dragged in. The K-wire is removed when the screw is approximately three quarters of the way across the vertebral body. The screw direction is checked with the C-arm as it is being advanced into the vertebral body until the tip penetrates the opposite cortex for bicortical purchase (Fig. 6). The rib heads are used as a reference for subsequent screw placement to fashion a screw lineup that later produces just the right amount of derotation commensurate with the patient's deformity.

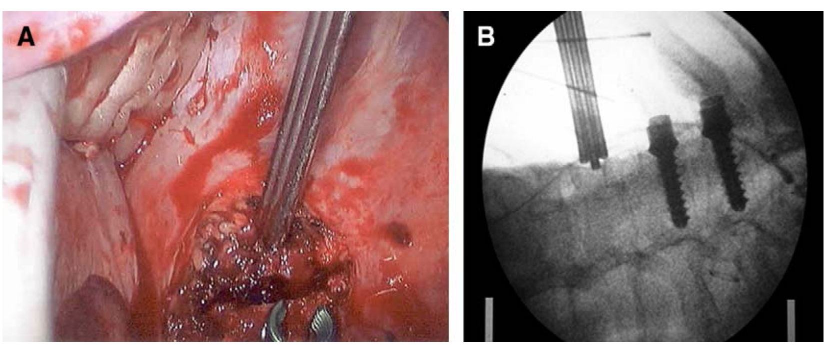

Fig. 5. (*A*) Intraoperative view through the endoscope shows the K-wire guide inserted onto the vertebral body. (*B*) PA C-arm image of the K-wire guide positioned on the vertebral body parallel to the end plate ready for the K-wire to be placed through the superior cannula.

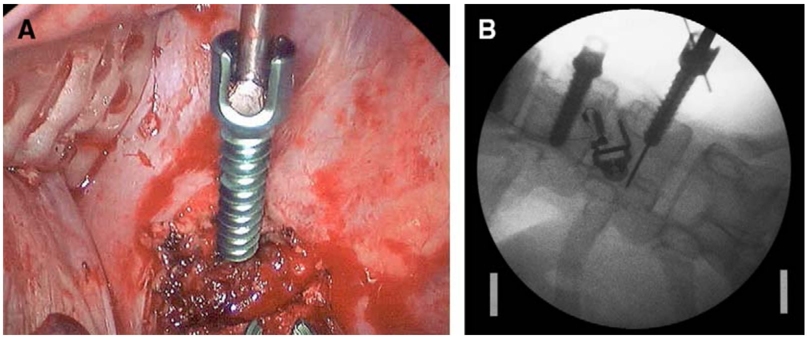

Fig. 6. (*A*) Intraoperative view through the endoscope shows a screw placed over the K-wire ready to be inserted into the vertebral body. (*B*) Photograph of intraoperative C-arm shows the K-wire in the vertebral body and the screw partially inserted into the vertebral body parallel to the end plates.

The technique for dual-head screw insertion is basically the same, with the exception of the use of an awl staple. The awl has been redesigned and now is able to hold a four-prong staple that is screwed onto its end. The staple and awl assembly is introduced through the portal to be cannulated over a previously inserted guidewire, or the awl action is started freehand at the center of the vertebral body in front of the rib head (Fig. 7). The staple is then tapped into place with a slap hammer, and once it is seated on the vertebral body, the awl is removed by turning the handle counterclockwise to disengage it from the staple (Fig. 8). With the larger dual-head screws, the portals have to be temporarily removed before the screws can be inserted through the portal incisions (Fig. 9).

One important technical note is that the screw heads need to be precisely aligned in a smooth arc formation. If one screw is more than a few millimeters deeper than the rest of the screws, reduction of the rod into that screw head may be difficult.

Once all the screws have been placed, the intradiscal Surgicel is removed and the end plates are rerasped to prepare for acceptance of the bone grafts. This is the most important part of the operation. A small amount of graft is first loosely nudged into the disc space, and the rasp is then used to push the graft all the way to the opposite side until, with the alternate addition of more graft and gentle compacting with the rasp, the disc space is completely backfilled. A mound of graft is also laid over the disc space and the previously denuded edges of the vertebral bodies, and, finally, the elevated periosteum is allowed to drape over the bone graft (Fig. 10).

Next, the rod length is determined using the endoscopic rod measurer, which is a cable that slides through a fixed end that functions as a scale.

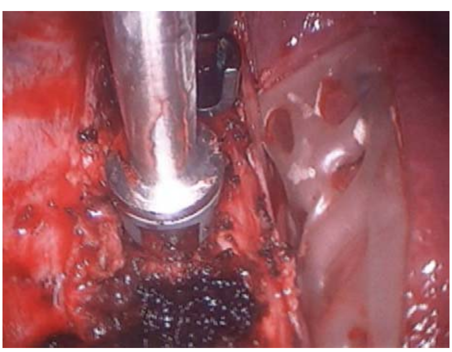

Fig. 7. Intraoperative view via the endoscope with the cannulated awl staple holder placed onto the cortex of the vertebral body.

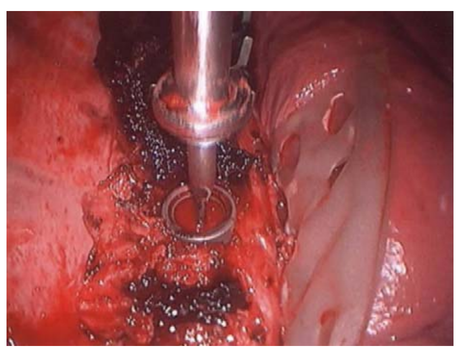

Fig. 8. Intraoperative view via the endoscope with the cannulated awl staple holder disengaged from the staple after a starting point has been made by the awl.

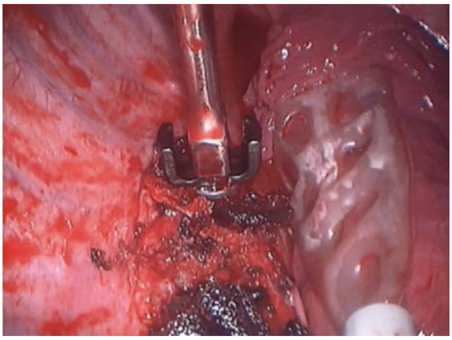

Fig. 9. Intraoperative view via the endoscope with an Eclipse dual-head screw into the vertebral body.

The free end of the cable is affixed to the uppermost screw, and the fixed end is affixed to the lowermost screw while the cable is pulled tight. The reading on the scale is the rod length (Fig. 11).

The 4.5-mm rod is cut to length and inserted into the chest cavity through the most inferior portal. The rod has slight flexibility and is not bent before insertion. It is manipulated into the inferior screw until its end is flush with the saddle (Fig. 12). This is done to prevent a section of rod from protruding and puncturing the diaphragm. Once the rod is in the lowest screw, the plug introduction tube is placed over the screw to guide the plug and hold the rod in position. The plug is introduced into the screw and tightened.

The rod is then sequentially reduced into each successive screw head with the rod pushers. The respective plugs are inserted into the screws as the rod is being reduced and provisionally tightened.

For the dual-head screw technique, two rods are cut to the same length. The first rod is inserted into the posterior screw heads (Fig. 13), and its reduction is the same as for a single rod. Once the first rod is in place, the second rod is inserted into the anterior screw heads. Because the spinal deformity is now mostly reduced by the first rod, the second rod drops into place without much trouble (Fig. 14).

Compression

Once the rod is seated and all the plugs are provisionally tightened, compression is begun at the inferior end of the construct and sequentially worked upward (Fig. 15). For the dual-head screw system, compression of the first rod is started once the first few plugs have been inserted for the second rod so as to save time. Because the diaphragm has to be retracted for work in the lower end of the construct, performing compression correctly when rod reduction is being done also saves the trouble of having to provide exposure of the same area twice. The second rod is reduced, invested with plugs, and compressed in the same manner as the first rod (Fig. 16).

Closure

Once compression is completed, all the instruments are removed, and a number 20 French chest tube is placed through the inferior portal before closure of the portal incisions (Fig. 17). AP and lateral radiographs are obtained, and the patient is transferred to recovery.

Postoperative regimen

The patient is kept in the intensive care unit (ICU) overnight before being transferred to a regular floor, where a custom thoraco lumbo sacral

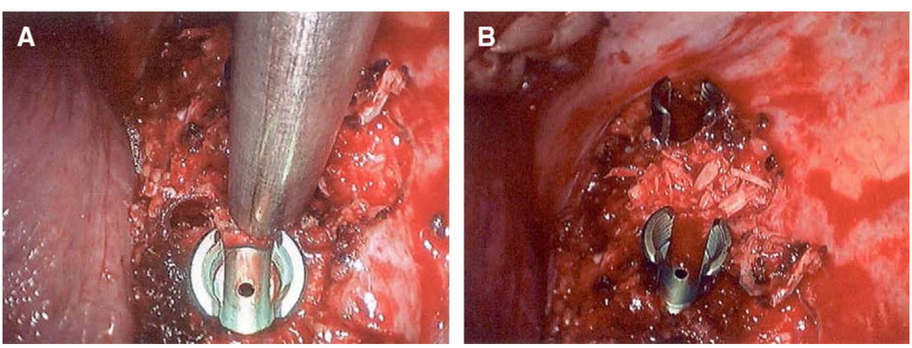

Fig. 10. (*A*) Intraoperative view through the endoscope shows the bone graft funnel inserted into the disc space. (*B*) Intraoperative view demonstrates a disc space filled with bone graft and graft placed over the adjacent vertebral bodies.

Fig. 11. Schematic view of all the screws in place with the endoscopic rod measurer inserted through all the screws.

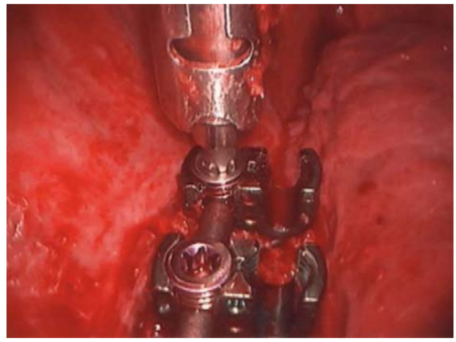

Fig. 13. Intraoperative view via the endoscope with the rod inserted into the posterior tulip of the dual-head screws, with all the plugs inserted.

orthasis is fitted, to be worn for 3 months. The chest tube is removed when drainage is less than 75 mL per 8 hours. The patient is firmly encouraged to walk right afterward and is discharged when able to ambulate independently. Follow-up visits with radiographs are scheduled for 1, 3, 6, and 12 months (Figs. 18–20).

Results

Since 1996, we have performed more than 500 cases of endoscopic correction and fusion for scoliosis at the Kaiser Sacramento Spine Center. The patients' ages ranged from 8.9 to 42 years. The results of the first 100 patients are reported below.

Because of the newness of the technique and the instrumentation, the mean operating time for the first 30 cases was 6 hours and 6 minutes, with a range of 2.8 to 8.5 hours. For the subsequent 70 cases, the mean operating time had been shortened to less than 3 hours.

Successful fusion was determined by the presence of bridging bone between the end plates confirmed on the AP and lateral radiographs. There were 14 nonunions in the entire series of 100 patients, but 9 of these occurred in the first 15 patients, who happened to have received Grafton

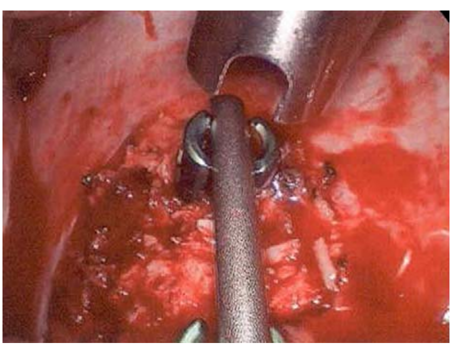

Fig. 12. Intraoperative view via the endoscope of the rod as it is inserted into the most inferior screw with the plug introduction tube about to be inserted over the screw.

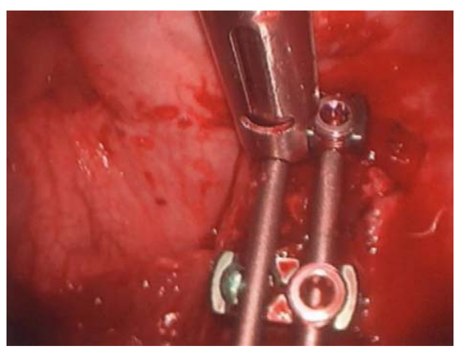

Fig. 14. Intraoperative view via the endoscope with the anterior rod inserted into the anterior tulip of the dual-head screws.

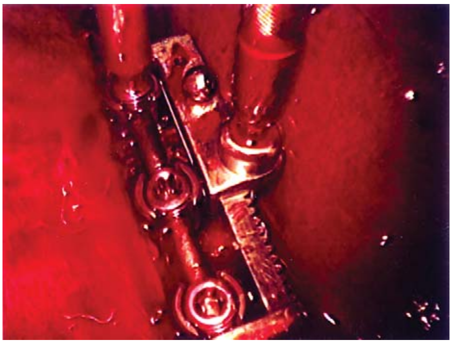

Fig. 15. Intraoperative view via the endoscope with the endoscopic compressor on the rod compressing two screws together.

bone graft substitute (Osteotech, Eatontown, New Jersey) for their fusion. The next 85 patients had an autologous rib graft, and only 5 of these developed nonunion. The use of autologous bone graft is now our standard practice.

All patients were taken off pain medication by the 1-month postoperative visit. Children returned to school between 2 and 4 weeks after surgery, and adults went back to work between 2 and 7 weeks after surgery.

Complications

There were a total of 39 complications in the first 100 cases, but none was considered to be serious. Fourteen patients developed pseudarthrosis: 9 in the Grafton group and 5 in the autologous group. Seven of the patients with Grafton nonunion and 2 of the patients with rib graft nonunion had breakage of their rods. Four patients (3 in the Grafton group) underwent posterior revision for progression of scoliosis or pain.

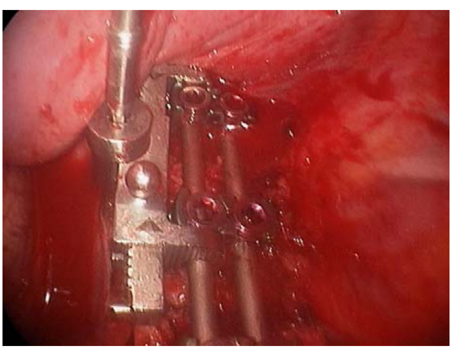

Fig. 16. Intraoperative view via the endoscope with the compressor at the distal end of a dual-head screw construct.

In one adult patient, a screw pulled out of the superior vertebral body, which led to loss of correction. The patient went on to posterior instrumentation and fusion.

Three patients experienced transient chest wall numbness. Five patients developed postoperative airway obstruction by mucus, three of whom required bronchoscopy.

There were two cases of complete separation of plugs and screws: one at the superior screw and the other at the inferior screw. In both patients, some correction was lost, but only one patient went on to nonunion, although remaining asymptomatic, and required no surgical correction.

One patient required wound revision. One patient developed a late pleural effusion that resolved spontaneously. Four patients developed intraoperative rib fractures during harvesting. Five patients had intraoperative "plow" of the proximal screw. Two patients had their chest tubes removed too early and needed thoracentesis.

Discussion

The endoscopic technique of instrumentation, correction, and fusion for scoliosis has undergone radical modifications at the Kaiser Sacramento Spine Center. During the pioneering phase, the cases were done with unlearned skill and rudimentary tools. With experience and specially designed instruments, our results have become better in almost all areas. The operating time has been significantly reduced. Considering our high early nonunion rate while Grafton bone graft substitute was being used, the nonunion rate since the adoption of autologous rib graft has decreased to five instances in 85 cases. Furthermore, the nonunion rate is practically zero in the following 85 patients as our technique became even more polished and the instruments were made more sophisticated and efficient.

Some key factors conducive to successful fusion, such as thorough discectomy and end plate removal, are common to endoscopic and nonendoscopic procedures. There are indeed special technical features in our endoscopic approach that clearly affect outcome, however, and their enumeration rightly chronicles the evolution of our experimental undertaking.

Poor screw placement was seen in many initial cases. Several of these screws did not have

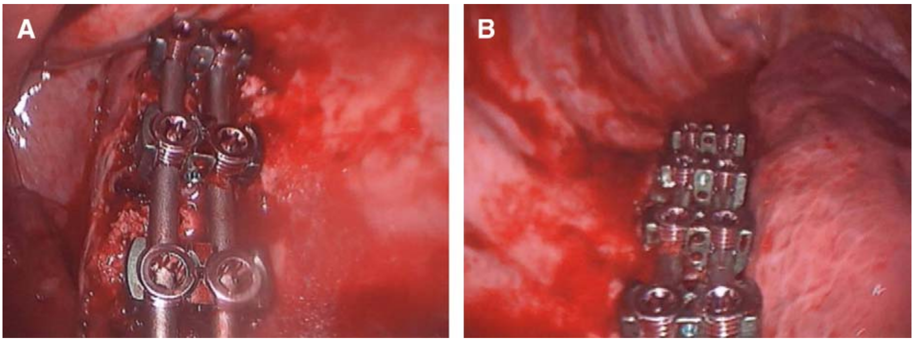

Fig. 17. (*A*) Intraoperative view via the endoscope of the distal end of a completed construct with the Eclipse dual-head screws. (*B*) Intraoperative view via the endoscope of the proximal end of a completed construct with the Eclipse dual-head screws.

bicortical purchase, and some were not seated well against the vertebral body, causing them to stand proud. Also, many of the most superior screws in the early constructs were inserted at an angle into the vertebral body, and this oblique orientation of the screws likely contributed to their pullout.

Early on, we struggled with selecting the optimal location for portal placement. In planning for a long fusion, accurate portal placement is critical. If placed inappropriately, the portal stems are levered against the ribs, and a significant amount of pressure and trauma may be inflicted on the intercostal neurovascular bundle. Patients may complain of postoperative dysesthesia over the anterior chest wall, which can last from weeks to months. Early in the series, portal placement was determined by visually compensating for the angle of rotation, which resulted in suboptimal locations. With the use of the C-arm, portals can be placed with great accuracy, and with better choices of portal locations, we no longer see cases of chest wall numbness and wound breakdown.

Development of mucous plugs in the ventilated lung was the most dreaded early complication.

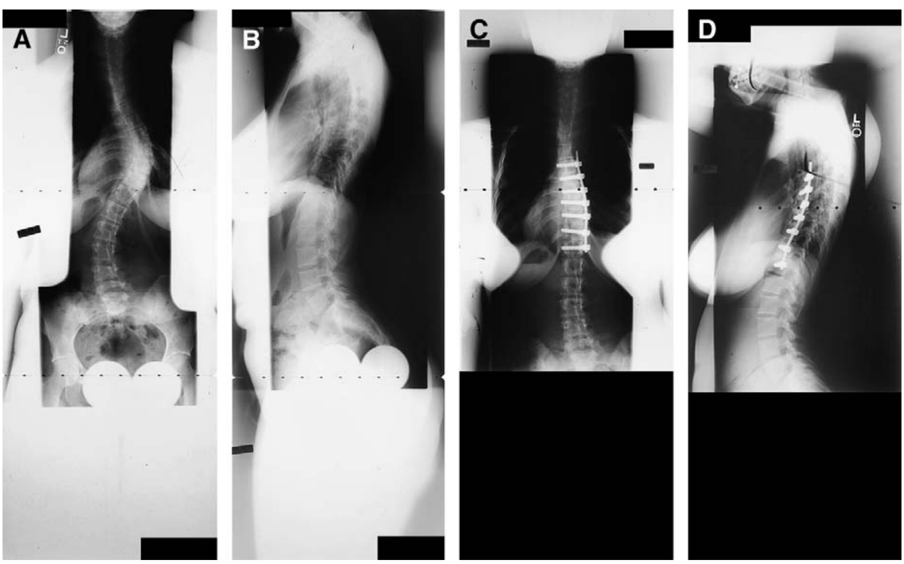

Fig. 18. (*A, B*) AP and lateral preoperative radiographs of a 19.2-year-old man with a 79° T6-to-T12 curve and a 39° T12-to-L3 curve. (*C, D*) Postoperative PA and lateral views of the same patient after endoscopic instrumentation, correction, and fusion.

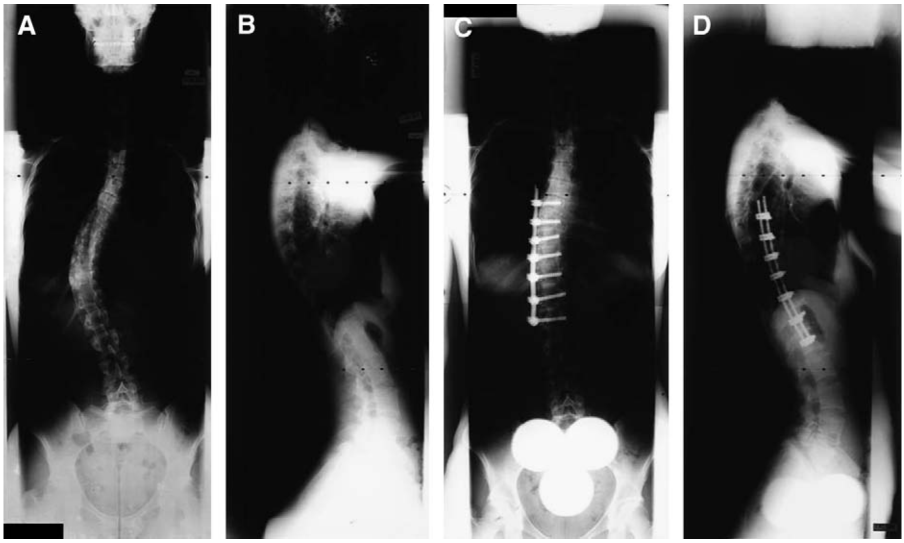

Fig. 19. (*A, B*) AP and lateral preoperative radiographs of a 26.9-year-old woman with a 53° T7-to-L1 curve and a 25° L1-to-L5 curve. (*C, D*) Postoperative PA and lateral views of the same patient after endoscopic instrumentation, correction, and fusion with the Eclipse dual-head screw system.

During surgery, the ventilated lung becomes hyperemic and increases its output of mucus. Pooling of secretion is also encouraged by the dependent position of the ventilated lung. The secretion eventually becomes organized and forms a mucous plug. To avoid this complication, the ventilated lung is fiberoptically suctioned before extubation. This new routine has completely eliminated this complication.

In a prospective study, Betz and colleagues [10] compared the efficacy of open anterior versus open posterior instrumentation in the treatment of idiopathic thoracic scoliosis. These authors demonstrated equivalent coronal correction and balance between the two techniques, with each being 59%, but most of the fusion lengths of the anterior group extended to L1, whereas in the posterior group, only 18% were fused to L1. Nevertheless, the anterior group demonstrated better correction in the sagittal profile than the posterior group with the patients who were hypokyphotic, with an average sparing of 2.5 lumbar levels. The pseudarthrosis rate for the anterior group was 5%, and for the posterior group, it was 1%. The estimated blood loss was 956 ± 837 mL for the anterior group versus 1197 ± 856 mL for the posterior group.

The curve correction rate in our early cases was unacceptably low. One reason was identified to be the inability to exert adequate compression to the construct. Once we made modifications in compressor design to boost compression, our average curve correction (in the last 10 cases) improved to a rate of 68.6%, which compared favorably with the 59% with open procedures reported by Betz and colleagues [10]. Another cause of poor correction was insufficient fusion length. We maintain that it is mandatory to fuse the Cobb angles and that anything short of that leads to failure. Even with that stipulation, all our fusion levels ended above L1, and we were thus able to preserve important motion segments.

A major advantage of the endoscopic technique over open procedures is less blood loss. In the series of open procedures reported by Betz and colleague [10], blood loss averaged 956 mL in the anterior group and 1197 mL in the posterior group. In our series, the average blood loss was 259 mL. None of the 100 patients needed blood transfusion, and we no longer require blood donation for our patients undergoing endoscopy.

Another area of significant improvement with endoscopy is the amount of postoperative pain. All patients who had endoscopic surgery were taken off all pain medication by 3.5 weeks, and many were taken off pain medication at the time of discharge. In comparison, our own patients who had previously undergone an open anterior procedure for scoliosis required pain medication for an average of 9.2 weeks, and those who had a posterior procedure for scoliosis were taking

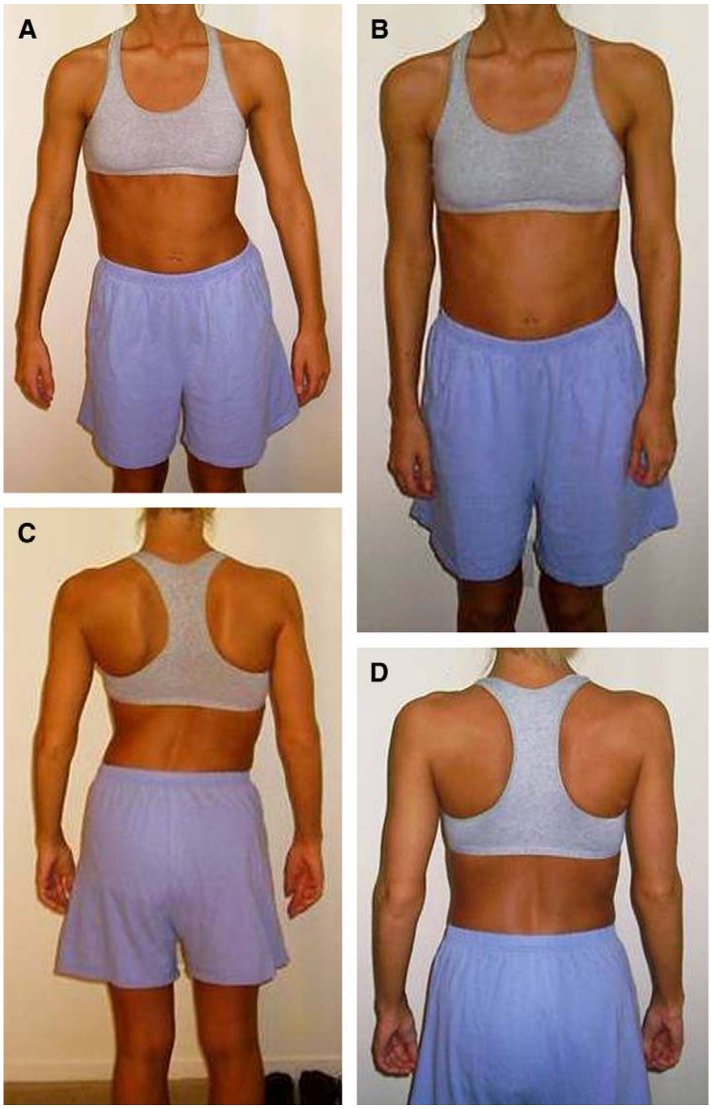

Fig. 20. Clinical preoperative (*A, C*) and postoperative (*B, D*) photographs of the patient in Fig. 19.

pain medication for an average of 8.4 weeks. Returning to baseline activity was also faster for the endoscopic group: all were back to school between 2 and 4 weeks, whereas children with open procedures were extremely resistant to returning to school before 12 weeks.

After having performed more than 500 endoscopic procedures for thoracic and thoracolumbar scoliosis, we still consider this technique a work in progress that can benefit from continued research. A recent example is our successful attempt to eliminate postoperative bracing with an innovative and unique implant, the CD HORIZON ECLIPSE dual-head screw (Medtronic Sofamor-Danek, Memphis, Tennessee). This apparatus has a single shaft with two conjoined heads. The one head, like the old single screw head system, allows a flexible rod to be easily reduced into the screws without stressing the bone-screw interface during curve reduction as would a stiffer rod; the second screw head accommodates a second more rigid "stenting" rod, which thus greatly increases the construct stiffness. Another application of the dual-head screw is at the proximal region of a dual-screw–dual-rod construct. Here, in the upper thoracic spine, the smaller vertebral bodies may not be able to sustain double screws. Instead, a single 7.5-mm dual-head screw can be used for each of the levels above T6 to T7 in conjunction with the dual-screw system for the lower thoracic segments. The small CD HORIZON ANTARES vertebral body staple (Medtronic Sofamor-Danek) is inserted at the level adjacent to the lowest dual-head screw; this staple helps to align the double rods into the same planes as the dual-head screws.

We are also currently working on several automated disc removal systems for rapid and thorough discectomy that are safe to use through the endoscope. We anticipate that these new devices should not only further reduce operating time and blood loss but improve fusion rate.

Thus, with practice, we become more adapt at the arch principles of endoscopic correction of scoliosis but never relax into complacency in executing any of the component tasks, because instrumentation and techniques tend to change so fast that no exact maneuvers are used more than a few times before being supplanted by newer and more proficient alternatives.

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