13 Pitfalls and Difficulties in the Surgical Management of Severe Adolescent Idiopathic Scoliosis

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Abstract

Different strategies have been used for surgical treatment of severe adolescent idiopathic scoliosis (AIS). It is risky for these patients to undergo aggressive operations, such as combined anterior-posterior surgery or posterior vertebral column resection. A posterior-only approach with less aggressive osteotomies is preferable, but a gradual preoperative period of traction is necessary. Preoperative halo traction is one method available, but there are controversies over its efficacy.

A two-staged posterior surgery using a magnetically controlled growing rod (MAGEC; Ellipse Technologies, Inc.) (MCGR) has been adopted in the last few years by the author. Its use has been preferred for gradual and safe correction of deformity. The MCGR is an internal distraction device, and hence a major advantage over halo traction.

The first surgery consists of a posterior aggressive release with Ponte osteotomies at many levels with high density pedicle screw instrumentation; an MCGR is implanted on the concavity of the scoliotic curve. A distraction is applied postoperatively to obtain gradual correction of the curve. The correction is performed over a series of distractions of the implanted device using an external magnet. In the second posterior surgery, the magnetic rod is removed and the definitive rods (generally three or four) are applied for definitive correction and fusion.

Keywords: severe adolescent idiopathic scoliosis, two-staged posterior correction, Ponte osteotomy

13.1 Definition of Severe Idiopathic Scoliosis

The definition of severe scoliosis is still controversial. O'Brien et al[1] consider a curve as severe when the Cobb angle is ≥70 degrees. Other authors[2] defined as severe a curve >80 degrees. Greiner[3] concluded that scoliosis is severe when the Cobb angle is >60 degrees, because significant respiratory symptoms are not present until the curve is around 60 degrees. It seems a more pragmatic definition of severe scoliosis is a curve with a Cobb angle > 80 degrees. In fact, the surgical procedure presents different and more demanding aspects: typically, it is a rigid deformity of the spine, with a low flexibility index on bending films (about 30%).

13.1.1 Preoperative Study

Surgical treatment requires accurate clinical and radiological evaluation of an adolescent with severe scoliosis.

The physical examination must be focused on excluding *non-idiopathic* cases of scoliosis, which generally require a different surgical approach to the deformity. Young age (>10 years) at onset of scoliosis, rapid progression of the curve, and mostly neurologic symptoms are important criteria used to differentiate the scoliosis from idiopathic cases. Neurologic deficits are not commonly found in the physical examination of severe adolescent idiopathic scoliosis; however, they should be tested and may be indicative of underlying neurologic problems. In severe scoliosis, deformity is also seen in the chest wall, resulting in poor pulmonary function. This is especially the case in curves >100 degrees, where pulmonary function is seriously decreased and presents higher risks for corrective surgery. Patients present with a low body mass and require nutritional supplements before surgery, as advised by a developmental pediatrician and a dietician.[4] Both the surgeon and the anesthesiologist must evaluate the cardiac system, which can be secondarily affected: a preoperative cardiac study must include electrocardiography, echocardiography, and stress testing.

The radiological study with standard standing X-rays is used to quantify the scoliosis curvature and to assess the flexibility of the deformity using traction films (generally the flexibility index is low, ≤30% in severe curves). It is also used to evaluate the extension of the arthrodesis and identify the presence of associated spondylolisthesis. The X-ray study must include the entire spine, including the cervical spine, for those patients who are going to be placed in preoperative traction. A CT scan of the entire spine is mandatory for studying pedicle anatomy and to assess for screw placement. Reconstruction of the axial images clarifies the complex anatomy of the scoliotic curve and allows the surgeon to visualize the levels of planned vertebral osteotomies or resections.[4] A CT scan can provide a three-dimensional (3D) study of the curved spine (▶ Fig. 13.1). An

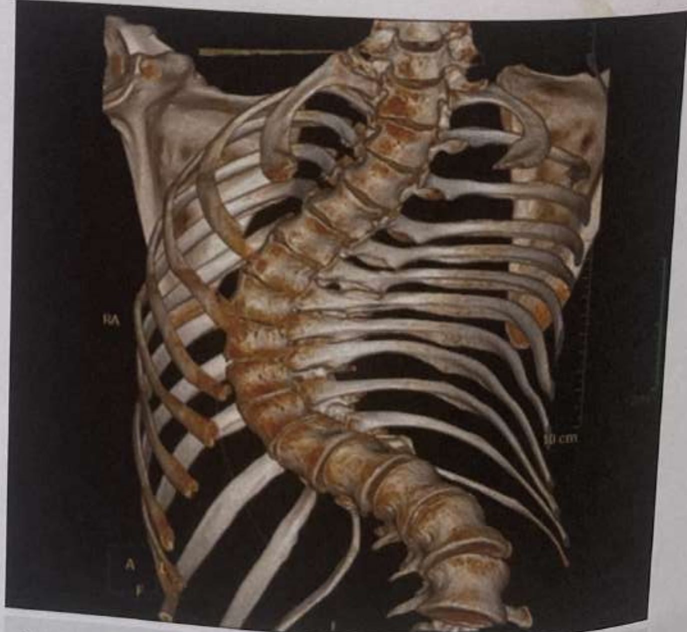

Fig. 13.1 A CT scan provides a three-dimensional study of the curved spine.

MRI scan is fundamental to assessing the neural axis, especially for those patients who are undergoing a large operative correction. It is important to exclude or to evaluate whether syrinx or Chiari malformations are present, as well as any stenosis or cord impingement secondary to severe deformity. If spinal stenosis is identified, some surgeons use CT myelography to understand the specific levels of compression. It is possible to have cord compression on the concave pedicle, which may require a resection of that pedicle with the remaining body. In cases of a planned aggressive osteotomy (e.g., a pedicle subtraction osteotomy), the blood flow to the spinal cord over the planned level of resection must be evaluated. In the future, MRI, contrast-enhanced gradient echo, and 3D pulse sequence may have a role in these patients.[4]

13.1.2 Preoperative Halo Traction

Traction can be utilized both before and immediately following anterior release and fusion, being removed after definitive posterior spinal fusion (▸ Fig. 13.2). It is now commonly used before posterior spinal fusion without anterior release. Halo traction represents the usual preoperative strategy employed to manage severe deformities to gradually straighten the spine before surgery. To prevent neurologic compromise after acute corrective maneuvers, the use of halo-gravity traction is advocated to allow for gradual curve correction and monitoring of neurologic function in the awake patient, which reduces the risk of permanent neurologic deficits.[5]

Preoperative traction has evolved considerably. After the halo-plaster vest, Stagnara[6] popularized halo-gravity traction utilizing a wheelchair for treatment of severe spinal deformity, noting some limitations to its use in cervical kyphosis and significant ligamentous laxity. Halo-gravity traction remains an often-used method and is safer than halo-femoral and halo-pelvic traction, which have a higher incidence of complications, such as hip subluxation or dislocation and sometimes femur fractures. Halo-gravity traction has the advantage in that it is transferable between the hospital bed, wheelchair, and walker (▸ Fig. 13.3).

Patients underwent local anesthesia for application of the halo ring, secured with eight pins. The initial traction force is about 2 kg and increased subsequently by 1 kg every day until the goal of 30% body weight is achieved. Daily neurologic control is performed. The patient is controlled for headache and motor and sensory function in all peripheral nerve distributions (including the cranial nerves). Traction is reduced at night, with the bed positioned in a slight reverse Trendelenburg position. Antibiotics are used in cases of pin-site infection. Every 5 to 6 days, X-rays are obtained in traction: possible overdistraction of the cervical spine must be avoided (▸ Fig. 13.3). The duration of traction is about 3 weeks. In the days immediately before surgery, traction is gradually reduced, and the patient will arrive at the operating room with a low traction of 2 kg. The halo is removed before surgery after induction of general anesthesia.

There are two mechanisms at work in correction of a scoliosis curve under traction.[7] The initial correction is due to the elastic properties of tissues: the elastic deformation is followed by a creep phase where most of the correction is achieved; this period of primary creep lasts for about 2 to 4 hours, with important correction. A secondary creep period allows a more gradual reduction of the spinal deformity, such that near maximal curve correction can be obtained after about 10 to 12 days. For this reason, the maximum scoliosis correction can be obtained after only 2 weeks of correction.[8]

However, the role of halo-traction and its safety and efficacy are actually the objects of discussion. For Koptan and ElMiligui,[7] traction increased curve flexibility compared to the curve seen in the supine side-bending films performed before traction. In the study by Sponseller et al,[9] there was no statistically significant difference between traction and control groups in coronal or sagittal curve correction, spinal length gain, blood loss, operating time, or complications; however, the patients who had halo traction less frequently had a vertebral body resection but achieved comparable and less demanding deformity correction. In our experience, halo

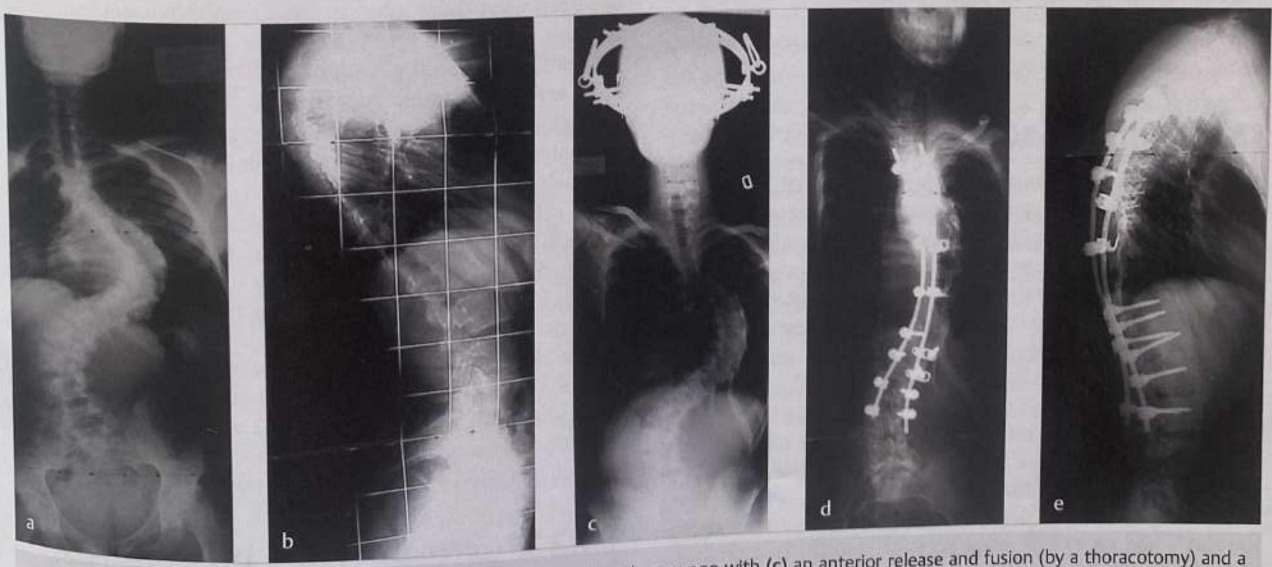

Fig. 13.2 A 17-year-old boy, (a, b) with severe idiopathic scoliosis treated years ago with (c) an anterior release and fusion (by a thoracotomy) and a post-operative period of halo traction. (d, e) Second surgery after removal of halo-traction consisted of posterior fusion with instrumentation (hybrid constructs with hooks and screws).

Fig. 13.3 Halo-gravity traction. (a) X-ray of the cervical spine: possible overdistraction of the cervical spine must be avoided. (b) A girl in traction in bed and (c) in the wheelchair.

traction resulted in a safer correction of the scoliosis, increasing the flexibility of the spine and of the chest, and improving pulmonary function. However, it had numerous problems, such as difficulties in daily activities, and possible complications, such as cranial nerve injuries or temporary brachial plexus palsies.

In conclusion, halo traction has been largely used in patients who have severe pulmonary dysfunction, severe spinal deformity, especially when previous surgery has been performed, and severe chest wall deformities and constriction. It is generally contraindicated with congenital kyphosis, with previous spinal cord tumor resections, with residual neurologic deficits, and when cord tethering is present. It is true, however, that traction without spinal release presents no advantage in comparison with immediate spinal fusion with instrumentation.

13.2 Surgical Treatment

Different surgical strategies have been used for severe adolescent idiopathic scoliosis (AIS).

13.2.1 Introduction

Originally, treatment consisted of posterior spinal fusion with Harrington instrumentation, combined with a prolonged period of preoperative halo-traction and respiratory rehabilitation.[10,11]

Later, the most common treatment was anterior release with an open thoracotomy,[12,13,14] followed by a posterior instrumented fusion (▸ Fig. 13.2). Halo-traction was often applied in the time period between the anterior release and posterior instrumentation (▸ Fig. 13.2, ▸ Fig. 13.3).[15] Sometimes, in highly rigid scoliosis, this combined program was preceded by an additional posterior release.[12] The correction rate of severe idiopathic curves with the combined treatment was about 45 to 47%, using Harrington instrumentation[13] or a multiple-hook construct[16]; 52% using Zielke instrumentation with a Harrington rod,[17] and up to 67% using anterior instrumentation and a posterior hybrid construct.[12] The combined anterior and posterior procedure was performed in one- or two-stage surgery according to different authors with different outcomes. Shufflebarger et al[16] found decreased hospital stay and operating time, fewer complications, and better correction in the continuous group compared to the staged group; instead Shen et al[18] concluded that there was no significant difference in safety or efficacy between the one- or two-stage groups. Additional anterior surgery requires increased time for general anesthesia and may have a negative impact on pulmonary function. Kim et al[19] reported that an open anterior approach may have a deleterious effect on pulmonary function for as long as 5 years postoperatively, after surgical treatment of adolescent idiopathic scoliosis. Video-assisted thoracoscopy, used for the anterior release, followed by posterior instrumentation for scoliosis treatment,[20,21,22] can minimize, but not eliminate, the negative effect on pulmonary function, as reported by Newton et al.[22]

Combined anterior and posterior vertebral column resection has been used more often to treat severe congenital and rigid scoliosis, and more rarely, idiopathic curves. This demanding procedure was used by Bradford and Tribus[23] for seven patients with severe idiopathic curves (mean Cobb angle 91 degrees) and achieved an average scoliosis correction of 59%. Suk et al[24] presented the results of vertebral column resection at the apex of the deformity performed through a single posterior approach in 16 cases (six of them with idiopathic curves) in curves >80 degrees, and with a flexibility of less than 25%; the procedure obtained a scoliosis curve mean correction of 59%, with complications in 4 cases, one of the four patients had permanent complete paraplegia. Since these studies were published, the use of vertebral column resection has increased. Recently Lenke[25] presented a paper on his large experience using this procedure, concluding that, when the deformity or imbalance is so severe that other osteotomies cannot correct the deformity, vertebral column resection offers the greatest potential correction.

13.3 Posterior-Only Procedures

The use of thoracic pedicle screws made it possible to reassess the role of posterior-only fusion as treatment for severe.

13.3.1 Pedicle Screws

Previous studies used posterior-only instrumentation with multiple hooks[26] or hybrid construct.[27,28] Burton et al used a varied combination of hooks, wires, and screws[28] in their treatment of patients with adolescent idiopathic scoliosis and thoracic curves between 70 and 90 degrees: They achieved an average curve correction of 64%, and concluded that these curves do not need anterior release to achieve acceptable results. The hybrid construct (thoracic hooks and lower screws) has been used by Arlet et al[27] in cases with thoracic scoliosis between 70 and 90 degrees and has achieved 54% correction.

However, the use of thoracic pedicle screws increased the interest for posterior-only fusion in deformity correction of large-magnitude scoliosis. Luhmann et al[29] compared combined treatment (anterior and posterior fusion) versus posterior fusion only in severe idiopathic scoliosis: they concluded that the patients treated with pedicle-screw-only instrumentation provided results similar to those obtained in patients with combined treatment (60.7% vs. 58.5%), without the negative effects of an anterior release on pulmonary function. Chang[30] used only posterior pedicle screw instrumentation in cases with thoracic scoliosis between 75 and 135 degrees, achieving a correction of 67%. Kuklo et al,[31] used 352 thoracic screws to correct idiopathic scoliosis >90 degrees, and achieved a 68% correction. The scoliosis correction rate of these two studies[30,31] adopting pedicle screws was surprisingly high, similar to that achieved by Bullmann et al,[12] using a combination of anterior instrumentation and a posterior hybrid construct. Most of the literature on the surgical treatment of severe idiopathic thoracic curves shows more contained values, generally lower than 60% regardless of the technique used.[2,17,23,24,27] In severe thoracic scoliosis the aim should not be to maximize the curve correction but to obtain an acceptable balance of the spine and reduce levels of fusion. Furthermore, the risks of a too aggressive posterior-only correction not preceded by an anterior release should not be underestimated. Overdistraction should be avoided, given the risk of spinal cord ischemia (▸ Fig. 13.4).[32] It has been reported that an intraoperative correction exceeding the preoperative bending correction was one of the factors related to an increased risk for spinal cord injury.[33]

Thoracic screw fixation can be potentially dangerous in the surgical treatment of scoliosis.[34,35] The technical difficulties in scoliotic deformities have been emphasized. In severe scoliosis, placement of thoracic screws may present further difficulties. However, the biomechanical advantages associated with their use make screws the ideal construct in large curves.[31] Thoracic screws on the concavity are the crucial anchor points for better scoliosis correction and restoring thoracic kyphosis.[36] Instead, the use of hooks at the apex of severe scoliosis has been shown to be both unreliable and dangerous; they are inside the canal and are thus invasive. It has been found that canal intrusion of a medially placed screw (with a 3-mm breach) is less invasive than a perfectly positioned pediatric laminar hook.[37] Therefore, hooks can sometimes be more dangerous than screws because of their position and can themselves cause complications.[38] Furthermore, hooks ensure a less rigid fixation, which can lead to dislocation during correction maneuvers or, subsequently, due to hook pullout with laminar fractures.

Neurologic complications are rarely reported in the literature in thoracic scoliosis treatment with pedicle screws,[39,40] although medially positioned thoracic screws are quite commonly reported.[41] Kuklo et al[31] reported screw accuracy of 96.3% in severe scoliosis by postoperative CT scanning: 10 screws had a breach of between 2 and 4 mm (three medial and seven lateral), whereas in 3 screws, the breach was 4 mm (two medial and one lateral). The two medial screws (0.57%) were the only ones removed, although there were no neurologic complications. Although the authors claimed that these screws would not be removed by today's standards, their acceptability remains controversial. According to some authors,[42] medial wall penetration ≤ 2 mm is well tolerated, and the screws can be considered acceptably positioned. Other authors[41] have hypothesized a 4-mm "safe zone" of medial encroachment (2 mm of epidural space and 2 mm of subarachnoid space). Still others[43] hypothesize a "definite safe zone" within 2 mm, a "probable safe zone" within 2 and 4 mm, and a "questionable safe zone" of 4 to 8 mm of medial encroachment. Recently, however, Liljenqvist et al[44] showed with MRI that the width of the epidural space was <1 mm at the thoracic apical level on the concave side. This means that there is no safety zone on the concavity; therefore, screw placement, especially at this level, should be very precise.

13.3.2 Posterior Staged Technique

Hui-Min et al[45] used temporary internal distraction as an aid in the correction of severe scoliosis as an alternative for situations in which halo traction is contraindicated. In their report, a temporary internal distraction procedure was performed.

The concept of using an internal distraction rod to correct the coronal and sagittal planes before definitive posterior fusion was suggested by Buchowski et al.[46] The authors implanted conventional growing rods in patients with severe curves and used two distraction procedures to perform a staged correction of the deformities. The use of growing rods for temporary internal distractions could facilitate curve correction by stretching the soft tissues safely. The results showed that only modest correction was found in the second distraction procedure. This phenomenon could be caused by progressive stiffness of the spine because of sudden and forceful distractions at irregular intervals. The main drawback of this procedure is the requirement of patients to undergo multiple operations for distraction of the implanted device. This can lead to high anesthetic risks, wound infection, and other surgical risks. Cheng et al[47] similarly employed two stages for the corrective procedure, first on the concave side by internal distraction of pedicle screws and rods through intramuscular tunnels in the first operation, followed by respiratory function exercises and improving nutritional status during the intervening period, and finally by additional posterior correction, ultimate instrumentation, and spinal fusion in the second operation.

13.4 Preferred Operative Technique

Correction of severe spinal deformities presents a very high incidence of risks related to neurologic deficits and to compromised

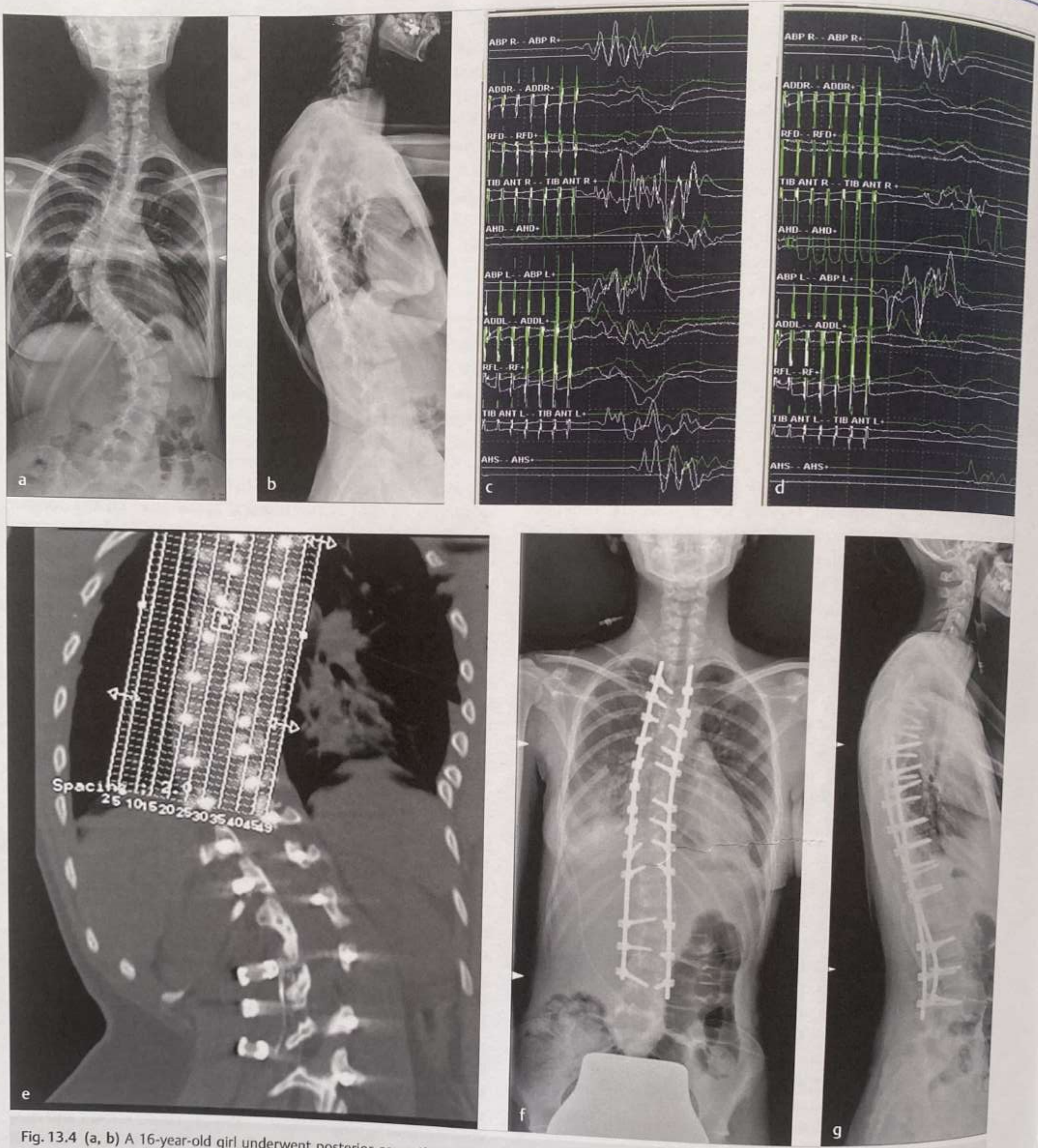

Fig. 13.4 (a, b) A 16-year-old girl underwent posterior correction without having undergone prior halo-traction. (c, d) Intraoperatively, there was a persistent and severe reduction in amplitude of somatosensory and motor-evoked potentials after scoliosis correction. The rods were removed immediately. The wake-up test resulted in a return to normal, and there was no deficit at the end of surgery. The surgery was terminated with the screws left inside. (e) CT scan done on the postoperative day confirmed the correct placement of the screws. (f, g) After a week a new surgery was performed for definitive correction without problems.

pulmonary function and malnutrition. It is, therefore, risky for these patients to undergo aggressive operations, such as combined anterior–posterior surgery and vertebral column resection. A posterior-only approach to the deformity with less aggressive osteotomies seems to be preferable for the patient. Similarly a posterior-only one-stage procedure can expose the patient to neurologic complications without a gradual period of traction. In severe scoliosis, our preferred strategy in recent years has consisted of a period of halo-gravity traction followed by posterior-only surgery (aggressive release with Ponte osteotomies at many levels and instrumented fusion) (► Fig. 13.5, ► Fig. 13.6). Preoperative halo traction is one method available, but there are

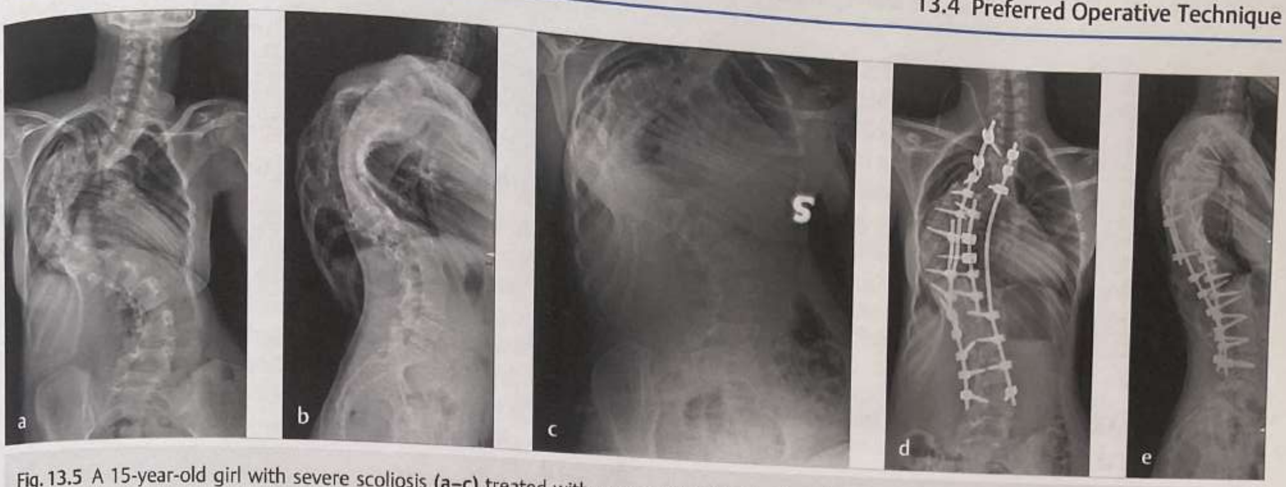

Fig. 13.5 A 15-year-old girl with severe scoliosis **(a–c)** treated with preoperative halo-traction: (X-ray after 21 days of traction). **(d, e)** Treatment consisted in a posterior instrumented fusion with aggressive posterior release and thoracoplasty.

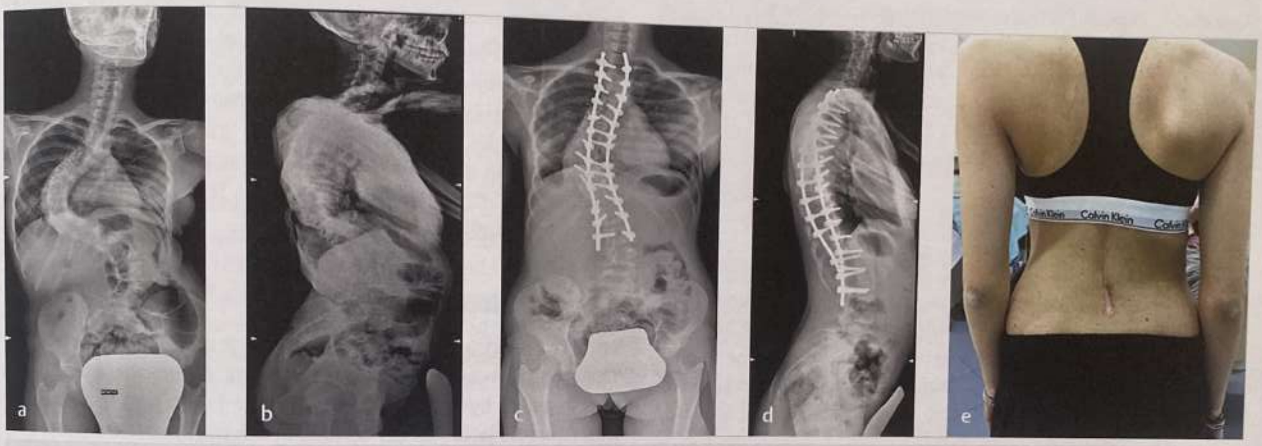

Fig. 13.6 A 14-year-old girl with **(a, b)** severe idiopathic scoliosis treated with preoperative halo-traction, and **(c, d)** posterior instrumented fusion with multilevel posterior release and thoracoplasty, with **(e)** a good clinical result.

controversies regarding its efficacy when compared with the non–halo traction group.[9]

To optimize surgical correction and minimize operative risks and complications, a two-stage posterior-only approach is safer for treatment of severe scoliosis. Internal distraction devices have been proposed for deformity correction. Some have adopted the use of conventional growing rods, and others have used intraoperative skeletal traction. These procedures can allow staged correction of deformities but may require multiple surgeries. In addition, intraoperative traction has been shown to lead to changes in the motor evoked potential (MEP).

13.4.1 Magnetically Controlled Growing Rod

The use of an MCGR(MAGEC; Ellipse Technologies, Inc.) has been proposed for gradual and safe correction of deformities. The correction is performed over a series of distractions of the implanted device using an external magnet.[48] This device has been studied in animals,[49] and it has been used in human subjects.[50] Cheung et al[48] report on the case of a girl with severe kyphoscoliosis and concurrent syringomyelia and Arnold–Chiari type 1 malformation treated with this novel approach, using the MCGR for gradual daily correction of the deformity. Although the original indication for the use of this device is to correct scoliosis deformities while allowing for spinal growth, it has been extended to gradual correction of severe spinal deformities by applying the technology of noninvasive distraction.

The MCGR is an internal distraction device and hence a major advantage over halo traction and growing rods because it can potentially be performed on an outpatient basis, thereby limiting the patients' hospitalization time, the time away from work for parents, and the number of operations required with the associated anesthetic and surgical risks.[48] In addition, the distraction is manually controlled and can be applied with the patient awake, which provides the best form of neurologic monitoring. Daily distraction procedures were performed to avoid progressive stiffness or autofusion of the spinal segments associated with growing rods. Preliminary clinical results of the MCGR in early-onset scoliosis have been published, and the results are promising.[51]

The procedure adopted by the author as the preferred method in the last years for problems related to the use of halo-gravity: a two-staged posterior surgery, using MCGR correction, was preferred.

The first surgery is a posterior aggressive release with Ponte osteotomies at many levels with screws implanted. A magnetic expanding rod is implanted on the concavity of the scoliotic curve. Later, in the postoperative period, a distraction is applied obtaining gradually correction of the curve. A CT study is used to evaluate the screws. In the second posterior surgery, the magnetic rod is removed and the definitive rods (in general three or four) are applied for definitive correction. The procedure is completed by thoracoplasty, and the bone chips obtained from resected ribs are used for definitive fusion.

13.4.2 Intraoperative Monitoring of Spinal Cord Function

Intraoperative monitoring of spinal cord function is mandatory in all patients by recording somatosensory evoked potentials (SSEPs) and transcranial electric stimulation–motor evoked potentials (TES-MEPs). A neurophysiologic change was defined as relevant when it consisted of a persistent unilateral or bilateral reduction in amplitude of 50% for SSEPs and of 65% for TES-MEPs compared with baseline. The wake-up test is performed intraoperatively in only a limited number of cases due to particular technical difficulties in acquiring the evoked responses.

13.4.3 First Posterior Surgery

The first posterior surgery is characterized by exposure of the posterior elements of the spine. In this first procedure, the surgical steps are placement of screws, aggressive release (Ponte osteotomies) and sometimes thoracic pedicle subtraction osteotomy at the apical vertebra, and implantation of the MCGR.

Screw Placement

The use of thoracic pedicle screws has become increasingly widespread in the treatment of scoliosis and has led to a significant improvement in deformity correction, even in large-magnitude curves. However, the use of thoracic screws in scoliosis remains controversial because of the technical difficulties and the risk of complications.[34] Various techniques are used to make thoracic pedicle screw placement safer, from guide pins inserted into the pedicles[40] to the C-arm intensifier,[52] from triggered electromyography[53] to image-guided systems based on CT.[54] Electromyographic monitoring appeared to be of limited value in the thoracic spine: in the study by Reidy et al[53] postoperative CT showed that 8.8% of screws had breached the walls of the pedicle; thus the monitoring had not significantly improved the reliability of safe thoracic screw placement. Computer-assisted screw pedicle installation permitted increased accuracy in placing screws and thus decreased the incidence of misplaced screws,[54] but the method entails preoperative CT scanning, high costs, and a longer operative period.

Safe methods for thoracic screw placement include the "anatomical" techniques, such as the freehand method[55] and the open-lamina technique[56]; the latter provides direct visualization of the medial wall of the pedicle. A method similar to the open-lamina technique that is more economical in resecting the lamina is the mini-laminotomy,[57,58] which allows palpation of the borders of the thoracic pedicles with a spatula inside the canal. This procedure, combined with the freehand technique, is very safe for apical vertebra on the concavity. For the other levels a simple freehand technique is preferred.

Mini-laminotomy Technique

A mini-laminotomy is performed in the cephalad part of the lamina.[58] After excision of the spinous process, the ligamentum flavum is completely removed with a small portion of the lamina in the upper part. This technique allows for inspection with a spatula inside the canal of the superior, medial, and inferior borders of the pedicle, and is the first portion of the posterior release, which is then completed more laterally, once all screws have been placed. Gelfoam is applied to control bleeding from the canal.

Pedicle Entry Point

Besides the probe inside the canal, to determine the pedicle entry point, the well-known anatomical landmarks are used.[40] The entry point at T11 and T12 is checked at the junction of the bisected transverse process and lamina at the lateral aspect of the pars; for the vertebrae of the midthoracic region, the entry point is more medial and cephalad, whereas above the midthoracic vertebrae, the entry point tends to be slightly lateral and caudad.[40]

Screw Placement

The presumed pedicle entry point was prepared with a rongeur. The pedicle was entered using a small curet: the instrument was inserted by applying mild pressure for 30 mm in the proximal thoracic pedicles, for 35 mm in the midthoracic region, and for 40 to 45 mm for the lower thoracic pedicles, directed along the axis of the pedicle in the frontal and sagittal plane. The screw tract inside the pedicle was checked with a pedicle probe to palpate distinct bony borders. Pedicle screws were inserted with a slow and gentle force using a screw diameter corresponding to about 80% of the pedicle diameter. In severe scoliosis, a preoperative CT can be useful to evaluate diameter and morphology of the concave pedicle. The screw length was chosen to be about 70% of the vertebral body on lateral fluoroscopy. The direction of the screw is more convergent medially in the upper thoracic spine, whereas it was convergent in the midthoracic spine and quite straight at T11 and T12. Screw placement must be confirmed by fluoroscopy using the anteroposterior, lateral, and oblique views. The oblique view permits a further check for screw placement inside the pedicle and also for the tip of the screw and the anterior border of the vertebral body. That way, if the tip of the screw is beyond the anterior border of the body, it is immediately removed, its tract is palpated, and a new screw is inserted with the appropriate shorter length.

There is no consensus of opinion in the literature as to the criteria for determining which asymptomatic malpositioned screws must be revised and which must be observed. With regard to lateral malpositioned screws, they should be prophylactically revised, despite being asymptomatic, if they are in direct proximity to the thoracic aorta (<5 mm), due to the risk of possible subsequent vascular lesions; otherwise, malposi-

Fig. 13.7 Ponte osteotomy: (a–c) It is a generous posterior resection of the superior and inferior part of the lamina with the ligamentum flavum, with the complete resection of the superior and inferior facets bilaterally. Previously during exposure of the spine, spinous process and interspinous ligaments have been removed. At each level of a Ponte osteotomy, a gap of at least 6 mm is created.

tioned screws with moderate lateral cortical perforation (range, 3–6 mm) can be left where they are. On the contrary, long screws must always be removed. Medial wall penetration of 2 mm would appear well tolerated and the screws can be considered acceptably positioned, although in one study,[44] MRI revealed that the width of the epidural space was <1 mm at the thoracic apical level on the concavity. Our previous study[58] reviewed 115 consecutive patients who underwent posterior instrumented fusion in our department (1999–2001) performed by three different surgeons using 1,035 transpedicular thoracic screws. Eighteen screws (1.7%) were misplaced in 13 patients (11.3%). Postoperative CT was performed, however, in 25 of the 115 patients (21.7%) when standard and oblique postoperative radiographs raised well-founded doubts regarding the positioning of 30 screws. Therefore, compared with the 311 screws examined by CT, these 18 misplaced screws represented instead 5.7% (i.e., a much higher rate).

Posterior Release

After screw placement, the posterior release is realized using Ponte osteotomies at many levels (▶ Fig. 13.7). Ponte osteotomies are posterior shortening procedures introduced for Scheuermann kyphosis[59] treatment and subsequently used in the treatment of scoliosis. The procedure is realized through a generous posterior resection of the superior and inferior lamina with the ligamentum flavum as well as the complete resection of the superior and inferior facets bilaterally. Previously, during exposure of the spine, spinous process and interspinous ligaments have been removed at each level, leaving them in place for just the first three upper levels of fusion to avoid junctional problems. Thus, at each level of a Ponte osteotomy, a gap of at least 6 mm is created. On the concavity, during bone resection, a spatula must be insert to protect the cord. Large undercutting of the lamina is crucial to prevent spinal cord compression when the gaps created are closed during correction of scoliosis.

Pedicle Subtraction Osteotomy

A pedicle subtraction osteotomy (▶ Fig. 13.8) is performed at the apical vertebra of severe scoliosis presenting a main thoracic curve with a Cobb angle >100 degrees[60]; the procedure was preferred to apical vertebral resection, which involves the resection of one or more vertebral levels and presents higher risks for complications.

Fig. 13.8 Thoracic pedicle subtraction osteotomy. A pedicle subtraction osteotomy is performed at the apical vertebra of scoliosis presenting a main thoracic curve with a Cobb angle >100 degrees. A wide laminectomy is performed over the apical level with the entire lamina of the cephalad and caudal vertebrae being removed. The spinal cord and the emergence of the corresponding roots must be well exposed. It is better to remove both pedicles, not only the pedicle on the convex side, to provide a more effective correction.

A wide laminectomy is performed over the apical level with the entire lamina of the cephalad and caudal vertebrae being removed. The spinal cord and the emergence of the corresponding roots must be well exposed. Then the pedicles to be resected are encircled, and removal of the vertebral body is started (more aggressive on the convexity of the curve) by means of straight and curved curets through a lateral pedicle-body entrance. It is better to remove both pedicles, not only the pedicle on convex side, to provide a more effective correction. Finally a posterior-based closing wedge osteotomy is performed, quite similar to a lumbar osteotomy used for sagittal imbalance of the spine. It is very important to minimize epidural and osseous blood loss during this surgery, not only with careful subperiosteal stripping of the posterior vertebral elements, but also with the continuous use of adjunctive hemostatic agents. Before starting bone resection of the osteotomy, two short rods are implanted to stabilize above and below the level to be resected. Upon completion of the procedure, compression across the pedicle screws closes the osteotomy. The short rods can be left in the site.

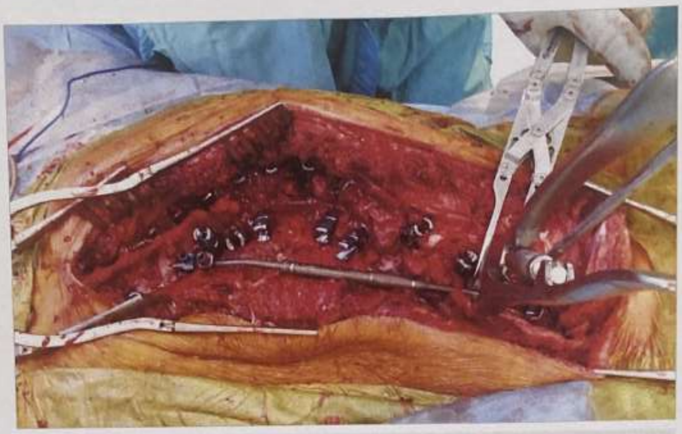

Fig. 13.9 A magnetically controlled growing rod is inserted on the concave side of the thoracic curve, in general between T3–T4 and L1–L2. A first distraction is performed intraoperatively. The other screws were preinserted for the later definitive correction.

Magnetically Controlled Growing Rod

Before implanting the MCGR, a very short convex rod (limited to the apical vertebra) is implanted in compression, in general in sites of multilevel aggressive release or eventually thoracic pedicle subtraction osteotomy (► Fig. 13.9). The other two short rods are implanted, one in the lumbar levels and the other in the upper thoracic site to align the spine.

The short convex rod is removed and the MGCR is inserted on the concave side of the thoracic curve, in general between T3-T4 and L1-L2. It is better not to prebend the rod to avoid harming the magnetic mechanism of the rod. Before implantation, it is necessary to distract the rod to confirm its effectiveness. A first distraction is performed intraoperatively. The other screws were preinserted for the later definitive correction. Surgery must be stopped for about 15 minutes to check MEPs and SSEPs, which must remain the same as baseline values. In cases of changed MEPs and SSEPs a wake-up test is performed prior to the end of surgery.

Distractions can start 3 days postsurgery (► Fig. 13.10). Distraction is started at 2 mm per day under screening using a CT control, at 7 days and again 14 days later. CT is also useful for controlling the correct screw insertion. At postoperative 2 weeks, 2 cm total distraction is obtained. In cases of back pain after distraction, the amount of daily distractions can be slowed to 1 mm distraction per day. The young patient is fully ambulant throughout all the distraction procedures and is able to perform the activities of daily living.

After postoperative 2 weeks, in general it is difficult to improve the scoliosis correction obtained and it is better to do the second phase of surgery: the advantage being a simple exposure of the spine. In general, the correction obtained after this program of distraction is around 40% of the scoliosis.

13.4.4 Second Stage of Posterior Surgery

The second surgery consists of removal of the MCGR and other temporary rods. The first step is to implant a short convex rod for a gentle maneuver of derotation. Then, the long concave rod and finally a long convex rod connected with the previous short rod are implanted. Again surgery must be stopped for about 15 minutes to check MEPs and SSEPs, which must remain at baseline values. In the case of changes, a wake-up test is performed before the end of surgery. After the definitive instrumentation and fusion of the instrumented area, a thoracoplasty is performed to improve the clinical result (► Fig. 13.11).

Fig. 13.10 Distraction of the magnetically controlled growing rod in the days after the first posterior surgery, using an external magnet.

Derotation

In severe scoliosis it is also possible to use direct derotation maneuvers. The flexibility index must be around, but not less than, 40%. In the direct vertebral rotation introduced by Lee et al,[61] during or after the concave rod rotation, screw derotators, which are inserted into the juxta-apical screws on the concave and convex sides, are rotated to the opposite direction of rod rotation. On the contrary, the vertebral coplanar alignment proposed by Vallespir et al[62] used slotted tubes attached to monoaxial convex screws.

The rod must be short and limited to the convex apical vertebra only. The idea of Vallespir et al[62] to consider derotation on the convex side of the scoliosis can be very effective in these severe curves. The derotation is done with an en bloc maneuver applied to the apical screws only: the convex screws are not tightened. Concurrently, an assistant applies a force on the rib prominence. Once the maneuver has been completed, the set apical screws are tightened. The entire derotation procedure requires about 20 minutes. The procedure cannot avoid thoracoplasty because of the incomplete effect of derotation on the severe rib hump. The direct rotation can expose the patient to neurologic risks: the use of SSEPs and MEPs is strongly recommended and avoids neurologic deficits. Monoaxial screws can significantly improve the vertebral derotation effect, as other authors have maintained,[63] but in severe scoliosis during derotation maneuvers screw pullout is possible, so uniplanar screws could be better to use.

Fig. 13.11 (a, b) A 17-year-old boy with severe idiopathic scoliosis, treated with a two-staged posterior surgery using a magnetically controlled growing rod (MCGR). The first surgery consists of a posterior aggressive release with Ponte osteotomies at many levels with implantation of screws. **(c, d)** An MCGR is implanted on the concavity of the scoliotic curve: later, in the postoperative period, a distraction is applied obtaining gradual correction of the curve. **(e, f)** In the second posterior surgery, the MCGR is removed and definitive rods are applied for definitive correction, completing surgery with thoracoplasty.

Definitive Instrumentation

Generally the definitive rod alloy implanted is titanium. Polyaxial screws are used for severe scoliosis in periapical sites to reduce the difficulties of rod capture. For the concave rod a cobalt–chrome alloy is sometimes preferred as its inherent stiffness permits a better correction of scoliosis curve and thoracic hypokyphosis. Different rods are implanted. A short one is applied on the convex apical vertebrae. A long rod is applied on the concavity of the curve. And a third, long rod is applied on the convexity of the scoliosis, connected with the previous short one.

Thoracoplasty

Thoracoplasty completes the surgery. The skin incision is the same as that for the previous procedure. The thoracolumbar fascia needs to be incised and elevated. A finger is slipped between the fascia and the paravertebral muscles. The fascia is then retracted toward the convexity of the curve over the rib deformity. The single ribs are then palpated, and the muscle covering the rib is incised with electrocautery, through to the periosteum. In general, four to six ribs must be incised. The periosteum must be pulled off the surface of the rib completely (upper and inferior edge of the rib). After that the periosteum is stripped underneath the rib. A Doyen elevator is passed: the rib is completely free from the periosteum, and the rib is resected with a rib cutter. The rib resection is around, but not more than, 4 cm to avoid a concavity where the original rib deformity was. It is important to resect different ribs and to reduce the length of resection in proximal and distal ribs. The suture of the periosteum and paravertebral muscles must be very accurate. The water test (Valsalva maneuver three times to see air bubbles to look for a leak in the pleura) is not always mandatory. Pleural effusion may develop postoperatively, without a leak, as the result of trauma to the pleura. It is better to insert a chest tube in every patient immediately at the end of the suture to avoid a quite painful and frightening thoracentesis for young patients days after surgery.

Finally the procedure is finished. No braces are used in the postoperative weeks due to the stability of the applied screw instrumentation.

13.5 Conclusion

In conclusion, to optimize surgical correction and minimize operative risks and complications, a two-stage, posterior-only approach can be safer for treatment of severe adolescent idiopathic scoliosis. The first surgery is a posterior aggressive release with Ponte osteotomies at many levels with implantation of multiple pedicle screws: an MCGR is implanted on the concavity of the scoliotic curve. Later, in the postoperative period, a distraction is applied to obtain gradual correction of the curve. The correction is performed over a series of distractions of the implanted device using an external magnet. In the second posterior surgery, the magnetic rod is removed, and the definitive rods are applied for final correction and fusion. Generally, a thoracoplasty is performed to improve the clinical result.

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