Anterior surgery for adolescent idiopathic scoliosis

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Abstract Anterior open scoliosis surgery using the dual rod system is a safe and rather effective procedure for the correction of scoliosis (50–60 %). Thoracic hypokyphosis and rib hump correction with open anterior rather than posterior instrumentation appear to be the better approaches, although the latter is somewhat controversial with current posterior vertebral column derotation devices. In patients with Risser grade 0, hyperkyphosis and adding-on may occur with anterior thoracic spine instrumentation. Anterior thoracoscopic instrumentation provides a similar correction (65 %) with good cosmetic outcomes, but it is associated with a rather high risk of instrumentation (pull-out, pseudoarthrosis) and pulmonary complications. Approximately 80 % of patients with adolescent idiopathic scoliosis (AIS) curves of $>70^\circ$ have restrictive lung disease or smaller than normal lung volumes. AIS patients undergoing anterior thoracotomy or anteroposterior surgery will demonstrate a significant decrease in percentage of predicted lung volumes during follow-up. The thoracoabdominal approach and thoracoscopic approach without thoracoplasty do not produce similar changes in detrimental lung volume. In patients with severe AIS ($>90^\circ$), posterior-only surgery with TPS provides similar radiographic correction of the deformity (44 %) with better pulmonary function outcomes than anteroposterior surgery. Vascular spinal cord malfunction after segmental vessel ligation during anterior scoliosis surgery has been reported. Based on the current literature, the main indication for open anterior scoliosis instrumentation is Lenke 5C

thoracolumbar or lumbar AIS curve with anterior instrumentation typically between T11 and L3.

Keywords Anterior spinal instrumentation · Adolescent idiopathic scoliosis · Pulmonary function · Anterior open scoliosis surgery

Introduction

Anterior spinal instrumentation for thoracolumbar and lumbar adolescent idiopathic scoliosis (AIS) was popularized by Dwyer [1] and Zielke [2] in the 1970s. The anterior approach has long been preferred in skeletally immature patients because it effectively prevents the crankshaft phenomenon [1, 2] and, historically, has been reported to produce better curve and rib hump correction and to save fusion levels distally. Another advantage of anterior spinal instrumentation is its ability to correct the thoracic hypokyphosis occurring in most AIS patients [3]. Alternatively, single cable/rod systems have the disadvantages of rod breakage, screw pullout, and a rather high risk of non-union. The risk of lumbar hypolordosis is evident when anterior instrumentation is used in the lumbar spine without interbody devices. In 1996, Kaneda et al. [4] introduced a dual-rod anterior spinal instrumentation and reported excellent outcomes in patients with thoracolumbar or lumbar and thoracic idiopathic scoliosis. Beginning in the 2000s, excellent outcomes were also reported for thoracoscopic anterior spinal fusion and instrumentation, but the long learning curve, unfamiliarity with thoracoscopic surgery, and longer operative time have restricted its large-scale use among orthopaedic surgeons. During this same period, posterior pedicle screw instrumentation for both thoracic and thoracolumbar idiopathic scoliosis with

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posterior Ponte osteotomies [5] gained large popularity due to a lower morbidity and better pulmonary function outcomes compared to anterior surgery, as well as similar radiographic outcomes.

Outcomes after anterior open spinal instrumentation for AIS

Several studies have documented that dual rod systems provide a safe and rather effective correction of scoliosis (50–60 %) in patients with thoracic, thoracolumbar and lumbar curves (Fig. 1) [4, 6, 7]. This structural curve improvement has been associated with thoracic hypokyphosis correction (about 10°; [6, 7] and a significant spontaneous correction of the non-structural thoracic (37 %; [7]) or thoracolumbar (48 [7]–51 % [6]) curve, respectively. In patients with juvenile idiopathic scoliosis, the arrest of anterior spinal growth may lead to an overkyphosing effect. The ability to horizontalize the lowest instrumented vertebral body, especially in the lumbar spine, is remarkable in anterior dual rod dual screw instrumentations. Screw placement should be in the mid-vertebral body in the upper and lower vertebrae, but slightly more posterior in the apical area to allow excellent

Fig. 1 Anterior thoracoabdominal approach with segmental vessels ligated and discectomies performed

rib hump correction (Fig. 2). The risk of implant failure or screw pull-out appears to be extremely low with this instrumentation [7]. Tis et al. [6] noted a mean kyphosis increase of 15° in patients with Risser sign of <1. On the other hand, the sagittal profile of the lumbar spine has been one of the weak points of anterior spinal instrumentation, which has a limited ability to correct lumbar lordosis even with interbody devices [5, 7]. To minimize the kyphosing effect, interbody devices or other structural grafts should always be used when instrumenting below the L1 level.

Rib hump correction appears to be better using dual rod anterior instrumentation than posterior instrumentation [8]. However, the former approach for rib hump correction is somewhat controversial given the ability to derotate the spine using the current pedicle screw-based instrumentations.

The rate of superficial and deep wound infection appears to be significantly lower in patients having anterior spinal instrumentation (0.6 %) compared with posterior instrumentation (3.0 %) [9]. Additionally, the risk of non-union and implant breakage is relatively low with the former [6]. Despite the relative invasiveness of open thoracotomy or thoracoabdominal approaches, the risk of immediate pulmonary complications as well as of prolonged paralytic ileus have been relatively low [7].

Geck et al. [5] compared the outcomes of anterior dual rod versus posterior pedicle screw instrumentation for 31 matched pairs of patients with Lenke 5C AIS. In terms of major curve correction (84 vs. 67 %), loss of correction (3.4 vs. 9.4 %), ability to correct lumbar lordosis (17° vs. no change) and length of hospital stay, posterior pedicle instrumentation was the most beneficial approach; however, the length of instrumentation (5.7 vs. 5.2) was shorter for anterior instrumentation (Fig. 3).

In patients with severe AIS (>90°) posterior-only surgery with a total pedicle screw system has been found to provide similar radiographic correction (44 %) as anteroposterior surgery [10]. In extreme scoliosis (>120°) anteroposterior surgery may still be a viable option when major correction (>70 %) is anticipated (author's personal opinion). In this case the most common approach is a vertebral column resection in addition to discectomies. Alternatively, in two studies on children, an all-posterior vertebral column resection provided a mean of 60 % correction of the spinal deformity [11, 12].

Anterior spinal instrumentation usually involves unilateral segmental vessel ligation during surgery (Fig. 1). The spinal cord is supplied by two different arterial systems: (1) three longitudinal arterial trunks lying within the spinal canal and (2) the segmental arteries arising from the aorta [13]. The largest medullary feeder of the lumbar cord is the arteria radicularis anterior magna (artery of Adamkiewicz), which in 80 % of cases originates from a left segmental

Fig. 2 Anterior dual screw, dual rod instrumentation T11–L3 in place

artery between T7 and L4, with a predilection for the T9–T11 levels [14]. Bridwell et al. [15] reported that four (1.1 %) of 349 patients developed a neurologic deficit after anteroposterior surgery; in three of these patients the neurological deficit was related to a pure vascular etiology. In the series of Tsirikos et al. [16], only one of 346 consecutive patients developed a neurologic deficit related to segmental vessel ligation. It would appear that patients with revision surgery, hyperkyphosis or intraspinal anomaly are at the greatest risk for vascular spinal cord lesion. The use of temporary segmental arterial occlusion with spinal cord monitoring may prevent some of these lesions. At our Institution, we have had only one case of a purely vascular permanent spinal cord deficit from unilateral, right-sided, mid-thoracic four pair segmental vessel ligation in the middle of the vertebral body with changes in the spinal cord monitoring occurring at the end of the anterior release procedure; the patient was an adult with hyperkyphotic idiopathic scoliosis. In this case, temporary segmental vessel ligation would not have been saved the spinal cord.

Anterior thoracoscopic procedures

The thoracoscopic approach can be utilized for anterior discectomies and release but also continued for definitive anterior spinal instrumentation using single screw single rod instrumentation [17, 18]. The need for thoracoscopic anterior discectomies and release has dropped dramatically for two reasons. First, all posterior pedicle screw techniques allow excellent curve correction without

anterior procedures [10] and second, all pedicle screw instrumentation appears to control the crankshaft phenomenon rather well in children with open triradiate cartilages [19].

Anterior thoracoscopic instrumentation has provided good correction of scoliosis (mean 55–65 %) with an excellent cosmetic outcome, but the risk of instrumentation complications (proximal screw pull-out) and pseudoarthrosis has been rather high [20]. The learning curve appears to be steep and operative times significantly longer when compared with anterior open or posterior techniques [17, 18]. Pulmonary function outcomes and immediate radiographic outcomes were better, but the total scores on the Scoliosis Research Society (SRS)-22 health-related quality-of-life questionnaire were lower for the posterior instrumentation group (hooks or hybrid) than for the thoracoscopic technique [17]. In addition, the technique appears to be rather unforgiving, especially if not all screws are well aligned or if one of the fixation points is lost for any reason [18]. Thus, even the most experienced surgeons in this field has converted nearly completely to the posterior all pedicle screw technique, which allows better curve correction with less risk of implant failure [18]. However, there thoracoscopic techniques may still be useful in the future. One case report on an 8-year-old boy with juvenile idiopathic scoliosis showed excellent coronal curve correction on anterior growth modulation using a 4.5 mm-diameter polypropylene spinal tether, a procedure which potentially could be performed thoracoscopically, although in this case report it was performed by the open thoracotomy approach [21]. Spinal surgeons are waiting for future studies on this promising new technique.

Fig. 3 Preoperative standing Lenke 5C idiopathic thoracolumbar scoliosis. Bending radiographs demonstrating flexibility of the main thoracic curve. Standing postoperative posteroanterior and lateral radiographs

Pulmonary function in patients with AIS related to surgical approaches

Newton et al. [22] evaluated preoperative pulmonary function data in 631 patients with AIS. In this group, the mean percentage of the predicted forced vital capacity fell below the American Thoracic Society threshold for normal pulmonary function (80 %) once the magnitude of the main thoracic curve exceeded 70°. In addition, thoracic hypokyphosis and number of vertebral levels in the main thoracic curve all had negative associations with forced vital capacity. Similar findings were confirmed by Johnston et al. [23], who also noticed that patients having a preoperative brace treatment had significantly lower lung volumes than patients not having any brace treatment, although preoperative major curves were similar in the two groups. In 2005, Kim et al. [24] reported changes in the pulmonary function after different surgical approaches for AIS in 118 patients with a minimum 5 years of follow-up. Patients undergoing posterior spinal instrumentation with thoracoplasty, anterior open spinal instrumentation or combined anterior and posterior approach all had a significant decrease in their percentage-predicted forced vital

capacity and forced expiratory volume in 1 s. In contrast, patients with posterior spinal instrumentation without thoracoplasty demonstrated a slight increase in the absolute lung volumes and no significant changes in the percentage predicted lung volumes [25]. Later, several authors [26, 27] confirmed the negative effects of open thoracotomy or the thoracoscopic approach with thoracoplasty on pulmonary function. It has been estimated that more than 50 % of patients undergoing the open thoracotomy approach will demonstrate at least a 15 % decrease in pulmonary function tests at the 2-year follow-up [26]. The thoracoabdominal approach does not produce significant lung volume changes [27, 28]. The pulmonary function effects of thoracoscopic instrumentation without thoracoplasty are somewhat contradictory with one study reporting no effects [27] and others reporting detrimental effects (>15 % decline in pulmonary function tests) in about 15 % of patients [26, 29].

In contrast to anterior open approaches, in one study, 22 % of AIS patients operated upon using posterior total pedicle screw (TPS) instrumentation without thoracoplasty achieved a significant improvement in lung volume during the 2 years of follow-up [25]. The mean increase in

absolute forced vital capacity at 2 years postoperative in the TPS group was 0.28 l and the percentage predicted increase was an average of 4.5 %. In patients with severe AIS (>90°) posterior-only surgery with the total pedicle screw system provided better pulmonary function outcomes than anteroposterior surgery [10].

Recommendations based on the current literature

Based on the current literature, chest cage disruption should be avoided whenever possible in order to optimize pulmonary function recovery in the treatment of AIS. Total pedicle screw instrumentation with vertebral column derotation can be regarded as the golden standard technique for thoracic AIS, with a 70 % correction rate of scoliosis and improvement of pulmonary function [25, 30]. The main indication for open anterior scoliosis instrumentation is a Lenke 5C thoracolumbar or lumbar AIS curve with open thoracoabdominal approach with anterior instrumentation typically between T11 and L3. When instrumenting below the L1 level, the use of interbody cages or structural femoral ring allografts is recommended to avoid the kyphosing effect in the lumbar spine.

In patients with extreme AIS of 120°, anterior open/thoracoscopic discectomy and release with or without vertebrectomy may still be indicated. Vertebral column resection with pre- and perioperative halo-traction with all posterior surgery is technically a more demanding option for these extreme cases, but it allows effective correction (51 %) with less pulmonary complications [11, 12]. The use of temporary rod distraction is another alternative option. Vascular complications related to multilevel segmental vessel ligation should be kept on mind while performing anterior surgery on hyperkyphotic, adult or revision procedures.

Thoracoscopic anterior spinal instrumentation is still a viable option to correct thoracic AIS (Lenke I curves). However, the correction rate of scoliosis appeared to be less effective than posterior surgery with the TPS technique. In addition, surgical time and hospital stay are longer and pulmonary and implant complications are more frequent [20].

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Conflict of interest IH is working as a consultant for Medtronic and Baxter.

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