Adolescent Scoliosis Classification and Treatment

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KEYWORDS

• Adolescent idiopathic scoliosis • Lenke classification • Scoliosis • Pediatric spine deformity • Pedicle screws

KEY POINTS

- Adolescent idiopathic scoliosis (AIS) can be classified according to the Lenke classification system, which incorporates curve magnitude, flexibility, the lumbar modifier, and the sagittal plane.
- The Lenke classification serves as a guide with respect to level selection in patients with AIS.
- The widespread use of pedicle screws has resulted in most AIS being treated through a posterior approach.

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a spinal condition causing deformity of the spine in 3 dimensions: the coronal, sagittal, and axial planes. AIS is defined as any curve equal to or greater than 10° in the coronal plane[1,2] in patients 10 to 18 years old.[3] It is a diagnosis of exclusion after congenital, neuromuscular, neural, or syndromic causes of scoliosis have been ruled out. Preoperative magnetic resonance imaging is useful for ruling out neural causes of scoliosis, such as syringomyelia or Chiari malformation, although its use as a preoperative screening tool is controversial.[4,5] A genetic component has been described regarding the cause of AIS.[6–11] With an incidence of 11% among first-degree relatives,[12] it is not uncommon for a health care provider to manage multiple members of a family with scoliosis.

AIS affects approximately 2% to 3% of the adolescent population, but fewer than 10% of patients with AIS need treatment.[13] The higher the curve magnitude, the lower the prevalence and the higher the female/male ratio. Curves greater than 30° have a 0.1% to 0.3% prevalence and affect females 10 times more than males.[14]

For years, the King-Moe classification was the most widely used system for guiding treatment in AIS. Its shortcomings included classifying curves based only on the coronal plane and showing low interobserver reliability.[15] Also, only variants of the thoracic curve were described, leaving some other curve types such as thoracolumbar or lumbar curves unable to be classified by this system. The Lenke classification[16] addresses these shortcomings and is now considered the gold standard for classifying AIS and guiding treatment. In this article, the Lenke classification is used to describe the AIS types and the treatment options.

Treatment of scoliosis includes nonoperative management such as bracing of curves measuring 20° to 40° or progressing more than 5° per year. Larger curve magnitude, younger chronologic age, and Risser sign are associated with curve progression.[17] The literature has shown bracing to be more effective in patients with earlier Risser scores (0–1) and open triradiate cartilages.[18–20] The goal of bracing is to maintain curve magnitude throughout a patient's growth period, although conflicting evidence of its effectiveness have been reported.[18,19]

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Surgery is indicated when a curve is progressive despite bracing and generally when the curve reaches 45° to 50°. The main goal is to stop the curve from progressing, leading to potentially severe complications from an untreated curve, including pulmonary function and back pain. Other goals driven by the patients themselves are improvement of cosmesis. Quality of life studies as measured by the SRS-22 (Scoliosis Research Society 22) questionnaire have shown that patients with AIS have lower self-image and are more self-conscious about their general appearance than the general population.[21,22] This finding can be related to a shoulder imbalance, rib prominence, or trunk asymmetry. Thus, the psychological impact of the deformity must also be taken into account when considering surgery.

The goals of surgery are to restore coronal and sagittal balance, reduce the rib prominence, and achieve shoulder balance. However, another important goal is to leave as many unfused segments as possible to preserve motion in the lumbar spine. The specific treatment options are discussed further in this article.

Two approaches to AIS surgery exist: the anterior approach and the posterior approach; a combination of the 2 is also used. Some potential advantages to the anterior approach are saving fusion levels,[23,24] decreased prominence of instrumentation, and decreased risk of crankshaft phenomenon in a skeletally immature adolescent.[16,25] However, some studies have indicated morbidity related to decreased pulmonary function,[26,27] which seems to improve at 2-year follow-up.[28] The anterior approach can be used to fuse simple thoracic curves and can also be used to perform anterior release and fusion combined with posterior spinal fusion in stiffer and larger (>90°) curves, although similar curve correction can be achieved in these larger curves by the posterior approach alone.[29]

Since the development of pedicle screws, the posterior-only approach has become the mainstay of treatment of AIS. Pedicle screws provide a 3-column fixation that permits greater curve correction and improved derotation.[30] Even in the more severe (>90°) and stiffer curves, pedicle screw constructs with osteotomies render good correction,[29] thereby reducing the need for combined anterior and posterior approaches. The crankshaft phenomenon may also be reduced by using pedicle screws.[31]

However, pedicle screw placement has a learning curve, especially with the free hand technique.[32] With surgeon experience, the accuracy of pedicle screw placement improves, and the medial breach rate decreases.[33,34] Reported breach rates range from 1.6% to as high as 58%.[33–38] However, rates for neurologic and visceral injuries despite these breaches are low. Although hypokyphosis has been observed with posterior-only pedicle screw constructs,[39,40] long-term follow-up has shown good maintenance of correction and coronal and sagittal alignment.[31,41]

LENKE CLASSIFICATION

Overview

The Lenke classification for AIS was developed as a tool to help surgeons classify curve types and guide them in operative treatment.[16] The curve type (the major curve), lumbar modifier (A, B, and C, depending on the location of the center sacral vertical line [CSVL] in relation to the apical lumbar vertebra), and the sagittal profile (–, N, +) is used to determine a specific curve pattern. Although there are 6 Lenke curve types, a total of 42 curve patterns can be observed.

The basis of surgical treatment is to fuse only the structural curves. The curve with the largest Cobb magnitude is defined as the major curve, which, by definition, is structural. Curves with lesser magnitude (minor curves) can be structural or nonstructural, depending on the degree of their flexibility seen on bending films. Generally, minor curves are not considered part of the arthrodesis if they bend out to less than 25°. Focal kyphosis is also a criterion for considering a curve to be structural.

The Lenke classification differentiates King-Moe type 2 curves into Lenke types 1 and 3, helping surgeons select which curves are amenable to selective fusions (Lenke type 1) and those that require an extended fusion in the lumbar spine (Lenke type 3). Unlike the King-Moe classification, which considers only the coronal plane, the Lenke classification accounts for both coronal and sagittal planes and has been shown to have good interobserver reliability. However, the axial plane (a reflection of vertebral body rotation) is still not included in the Lenke classification. Moreover, some curve types such as curves with C lumbar modifiers are subject to controversy regarding selective versus nonselective fusion. The following section on the specific Lenke curve types includes some of the controversies and current recommendations for treatment.

Treatment of Lenke Curve Types

Lenke 1: single thoracic curve

For single thoracic curves (**Fig. 1**), it is generally accepted to perform selective fusions of the main thoracic curve, unless there is a kyphosis of more than 20° in the thoracolumbar area, in which case, the lumbar curve is also included in the

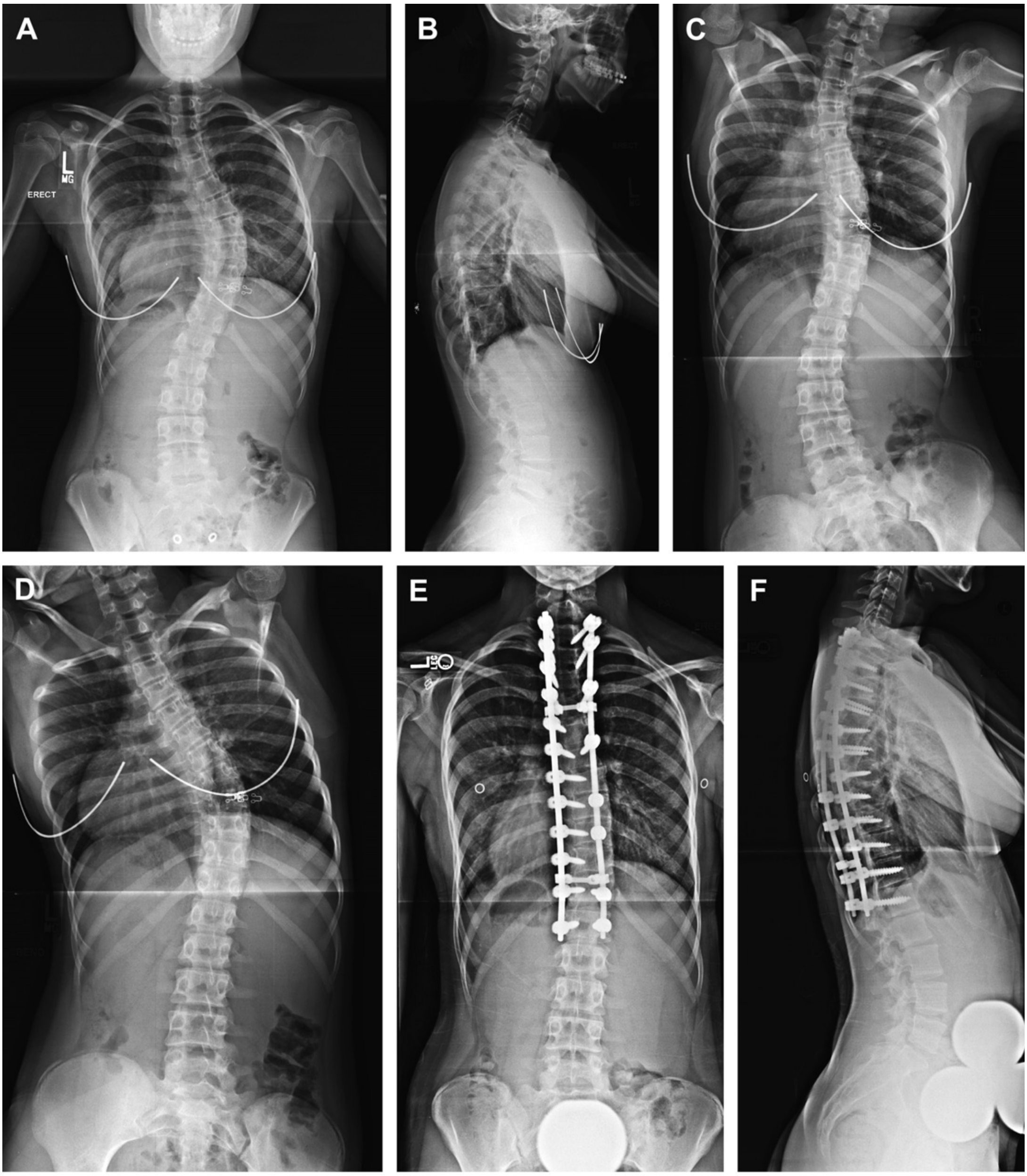

Fig. 1: Lenke 1. Preoperative standing posteroanterior (PA) (*A*) and lateral (*B*) radiographs of an 11-year-old girl with a right 50° main thoracic curve and a 25° left lumbar curve. Right (*C*) and left (*D*) bend films show that the main thoracic curve bends down to 28° and the lumbar curve bends down to 4°. Two-year follow-up PA (*E*) and lateral (*F*) radiographs show correction of the main thoracic curve to 15° and correction of the lumbar curve to 3° with posterior pedicle screws from T2 to L1.

fusion.[16] The unfused lumbar curve is nonstructural and usually spontaneously corrects itself after thoracic fusion.[42–46] It is important to note any preoperative shoulder height discrepancy, because this often determines the upper fusion levels. Shoulder height can be determined clinically as well as radiographically using the clavicle angle or T1 tilt.[47]

Three different scenarios exist regarding shoulder height. The first and most common scenario is a right main thoracic curve, with the right shoulder being higher than the left. In this case, correction of the thoracic spine also brings down the right shoulder, usually achieving equal shoulder height. In these cases, the upper instrumented level is usually T4 or T5.[48] If the left shoulder is elevated, the compensatory proximal thoracic curve is usually included in the fusion (to T2) to oppose the corrective forces being placed on the main thoracic curve, which would otherwise continue to drive the left shoulder up. If both shoulders are equal in height preoperatively, T3 is usually the upper level of fusion.

For single thoracic curves with minor flexible lumbar curves (Lenke 1A and 1B), selective thoracic fusions are generally indicated. For distal fusion levels, it is important to choose the appropriate lowest instrumented vertebra (LIV) so as to leave good coronal balance and avoid lumbar decompensation or progression of the primary curve (adding-on). Conventional guidelines have used the stable vertebra, or the most proximal vertebra with pedicles most closely bisected by the CSVL as the LIV.[15] However, this guideline was based on Harrington instrumentation, in which the corrective forces were uniplanar. With 3-column fixation using pedicle screws, an additional 1 or 2 distal motion segments can be saved, instead of fusing to the stable vertebra.[49]

The neutral vertebra is also used to determine the distal fusion level.[49,50] The relation between the neutral vertebra and the end vertebra can be used to ascertain the LIV. If there is no more than 1 level between the end vertebra and the neutral vertebra, then fusion to the neutral vertebra is sufficient. This level corresponds to 1 level proximal to the stable vertebra. However, if the neutral vertebra is 2 or more levels distal to the end vertebra, then the LIV is NV-1. If the neutral vertebra is the end vertebra, then it is adequate to fuse to the distal end vertebra. A 2-year follow-up by Suk and colleagues[49] in patients treated using these guidelines showed satisfactory results with good coronal balance, compensatory lumbar straightening, and no adding-on.

With regard to adding-on, Miyanji and colleagues[51] differentiated 2 types of Lenke 1 curves, depending on the L4 tilt: 1A-L (tilted to the left) and 1A-R (tilted to the right). 1A-R curves have been shown to have a higher risk of adding-on because of the overhanging curve pattern, requiring a more distal fusion, approximately 2 levels more distal than a 1A-L curve.[51,52]

Lenke 1C curves have been subject to ongoing controversy regarding their fusion levels because often they behave like double major curves. In the 1C pattern, the nonstructural lumbar curve is flexible (side-bending to <25°), in which the apex completely crosses the midline. A study by Lenke and colleagues[53] showed that selective thoracic fusion was performed in 62% of patients with 1C curves, implying that the remaining 38% had nonselective fusions. Newton and colleagues[54] reported that larger preoperative lumbar curve magnitude, greater lumbar apical vertebra displacement from the CSVL, and smaller thoracic/lumbar magnitude ratio were factors associated with nonselective fusion. Lenke and colleagues[55] reported that for a selective fusion to be successful for 1B and 1C curves, the thoracic/lumbar ratios for Cobb magnitude, apical vertebral translation, and apical vertebral rotation should be greater than 1.2.

Lenke 2: double thoracic curves

In treating double thoracic curves (**Fig. 2**), it is important to not overlook a structural proximal thoracic curve. Both the main thoracic and the structural proximal thoracic curves must be included in the fusion, according to the Lenke criteria for structural curves. Inappropriate distinction of a structural proximal thoracic curve leading to exclusion of the proximal curve from the fusion, especially in the context of a preoperative elevated left shoulder, can lead to severe worsening of shoulder imbalance and patient dissatisfaction. Suk and colleagues[56] reported improved results when both proximal and main thoracic curves were fused in patients with level shoulders or a higher shoulder on the side of the proximal thoracic curve. In patients with an elevated left shoulder, fusing to T2 as the upper instrumented level is usually sufficient to gain good correction of the proximal thoracic curve and achieve adequate shoulder alignment. In patients with level shoulders preoperatively, the upper level of fusion can be T2 or T3, depending on the correction and shoulder balance achieved intraoperatively. In general, fusion of both proximal and main thoracic curves is recommended for Lenke type 2 curves. Suk and colleagues[56] found that the proximal thoracic curve can be left unfused if the left shoulder is lower than the right by a difference greater than 12 mm.

To select the LIV, the distal fusion rules used for Lenke 1 curves can be applied to Lenke 2 curves. Using the NV and EV as landmarks, the LIV is generally the stable vertebra (the most proximal vertebra intersected by the CSVL).[48–50] Recommendations for selective fusions for type 2C are the same for 1C curves, where the ratio of the main thoracic/thoracolumbar/lumbar curves for Cobb magnitude, apical vertebral translation (AVT), and apical vertebral rotation (AVR) must be 1.2 or greater in curves lacking a focal thoracolumbar kyphosis 10° or greater.[55]

Lenke 3: double major curves

Lenke type 3 curves (**Fig. 3**) are those in which both thoracic and lumbar curves are structural,

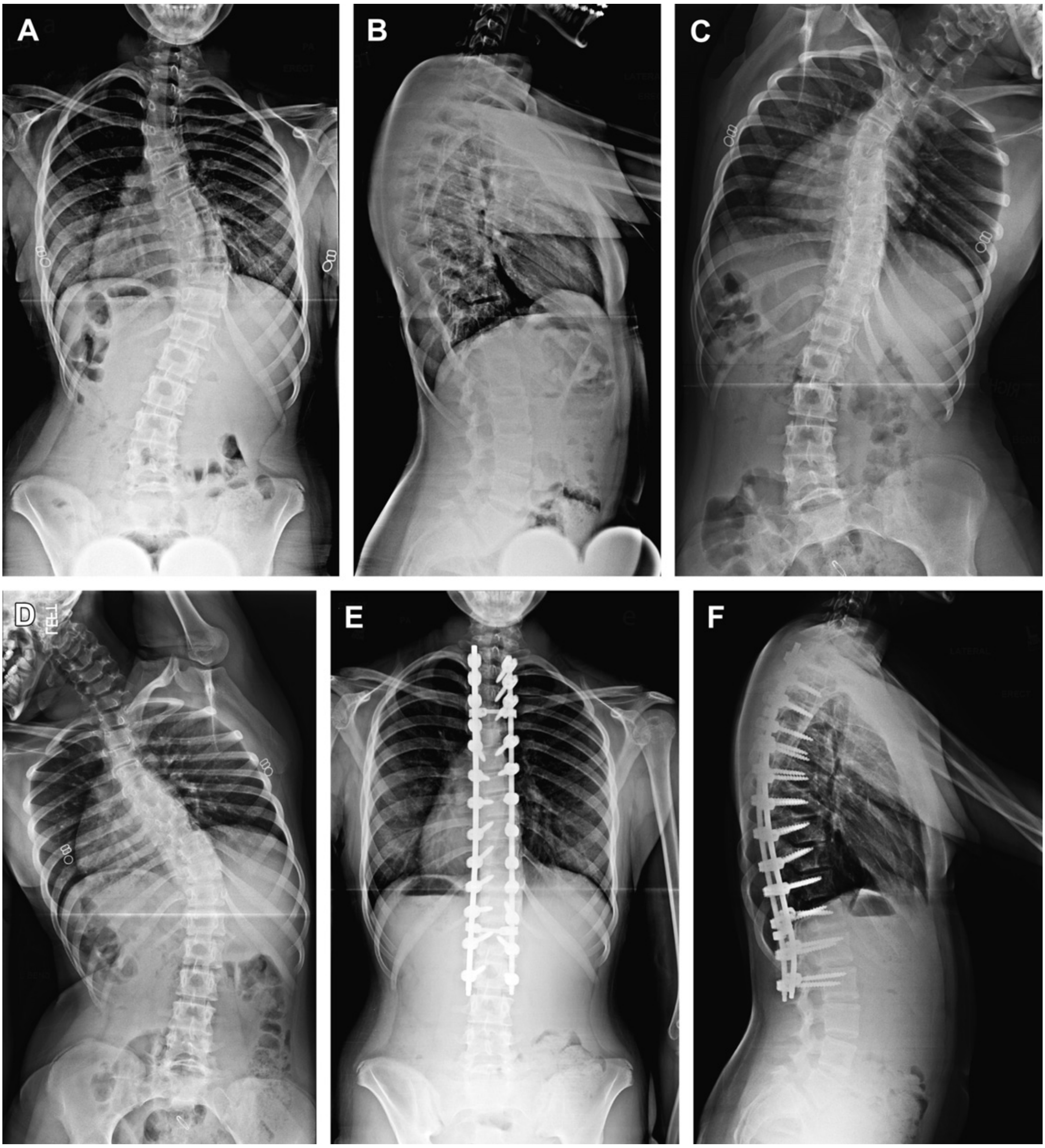

Fig. 2: Lenke 2. Preoperative standing posteroanterior (PA) (*A*) and lateral (*B*) radiographs of a 12-year-old girl with a right 45° main thoracic curve and a left 38° proximal thoracic curve. Right (*C*) and left (*D*) bend films show that the main thoracic curve bends down to 30° and the proximal thoracic curve bends down to 27°. One-month follow-up PA (*E*) and lateral (*F*) radiographs show correction of the main thoracic curve to 16° and correction of the proximal thoracic curve to 17° with posterior pedicle screws from T2 to L2.

so both curves are generally included in the fusion. Some confusion exists between Lenke 1C and Lenke 3 curves, because they can behave similarly, especially Lenke 1C curves with lumbar curves with a borderline nonstructural criterion (bending to slightly <25°).

The goals for double major curves include obtaining adequate correction and balance of both curves. Preoperatively, it is important to note any waist asymmetry or trunk shift in these patients, because the goal is to restore coronal balance. This balance is attained by centralizing and neutralizing the LIV. Also crucial in achieving coronal balance is making the LIV disk as horizontal as possible. It is also not uncommon to find hyperkyphosis in the thoracolumbar area (T10-L2), which should be corrected to achieve normal sagittal alignment. The upper instrumented

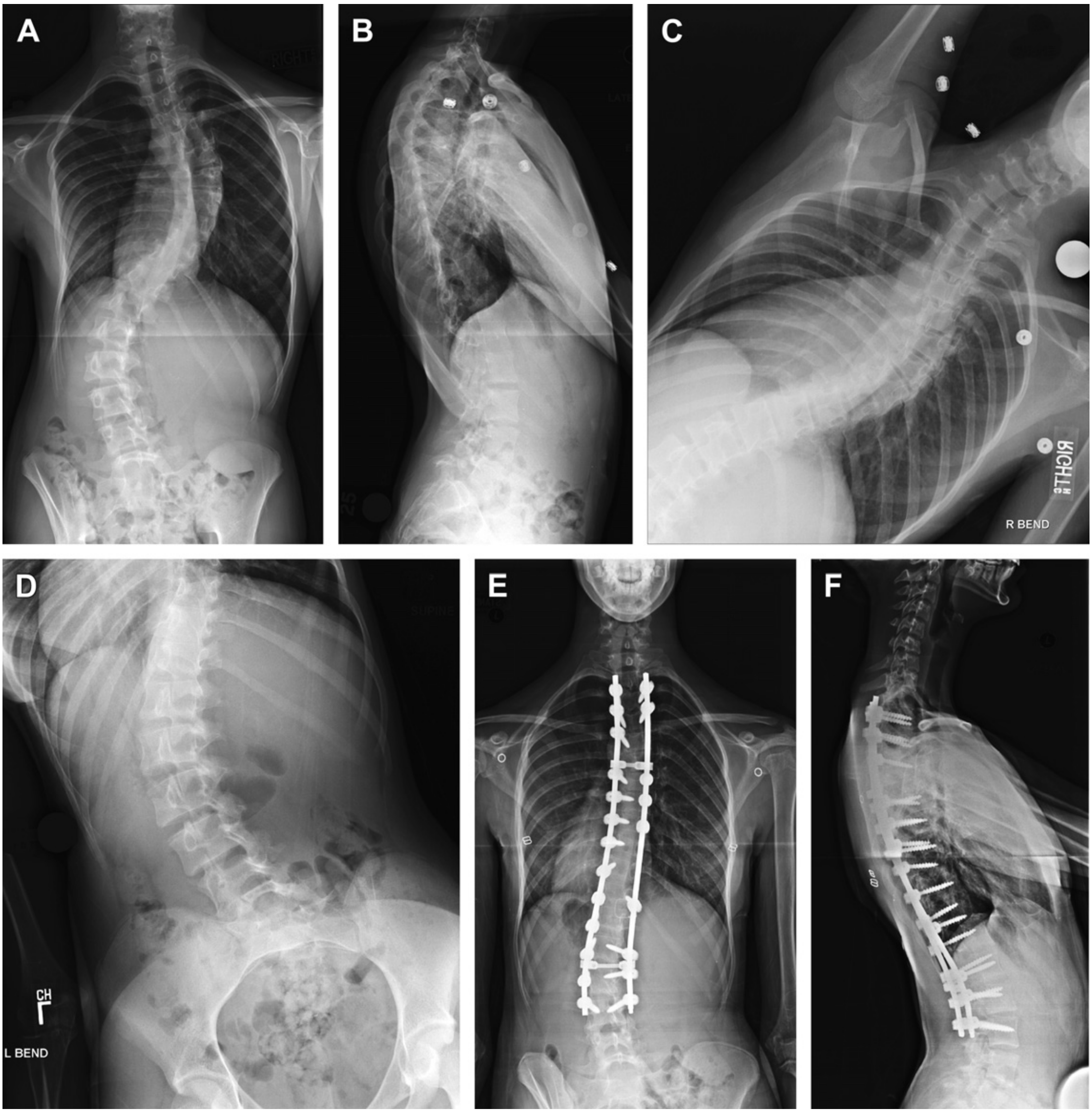

Fig. 3: Lenke 3. Preoperative standing posteroanterior (PA) (*A*) and lateral (*B*) radiographs of a 12-year-old girl with a right 72° main thoracic curve and a left 56° lumbar curve. Right (*C*) and left (*D*) bend films show that the main thoracic curve bends down to 56°, and the lumbar curve bends down to 40°. Two-year follow-up PA (*E*) and lateral (*F*) radiographs show correction of the main thoracic curve to 16° and correction of the lumbar curve to 18° with posterior pedicle screws from T3 to L4.

vertebra (UIV) is determined first by the magnitude and characteristics of the thoracic curve, but shoulder asymmetry and characteristics of the proximal nonstructural thoracic curve must also be considered before deciding the proximal level of fusion. This level usually corresponds to T3 to T5.

As a general guideline for the distal fusion level, the most proximal lumbar vertebra intersected by the CSVL is usually the LIV,[48] either L3 or L4. On posteroanterior standing films, if the apex of the thoracolumbar/lumbar curve is L2 or distal, the L3 to L4 disk space opens on the convexity, and if the rotation of L4 is Nash-Moe grade I or greater,[57] then the fusion should extend to L4. However, if the apex is the L1 to 2 disk or proximal, the L3 to L4 disk space closes or is neutral on the convexity, and the rotation of L3 is grade 1.5 or less, then the fusion can stop at L3.[57] Side-bending films can also be useful for deciding whether to fuse to L3 or L4. For a typical right-sided thoracic and left-sided lumbar curve, Suk and colleagues[49,50] recommend fusing to L3, if L3 crosses the CSVL in the left bending radiograph, or if the rotation of L3 in the right bending radiograph is less than Nash-Moe grade II. Fusion to L4 is recommended if L3 does not cross the CSVL on left bending films, or if L3 rotation is grade II or higher on the right bending films.

Selective thoracic fusion can be considered in some 3C curves in which the main thoracic curve is larger than the thoracolumbar/lumbar curve and there is an absence of thoracolumbar kyphosis from T10 to L2 of 10° or greater. The same main thoracic/thoracolumbar/lumbar ratio criteria of more than 1.2 described for 1C and 2C curves amenable to selective thoracic fusions is used for 3C curves as well.[55,57]

Lenke 4: triple major curves

Lenke 4 curves are those in which the proximal thoracic, main thoracic, and thoracolumbar/lumbar curves are all structural. All 3 curves should be included in the arthrodesis by means of

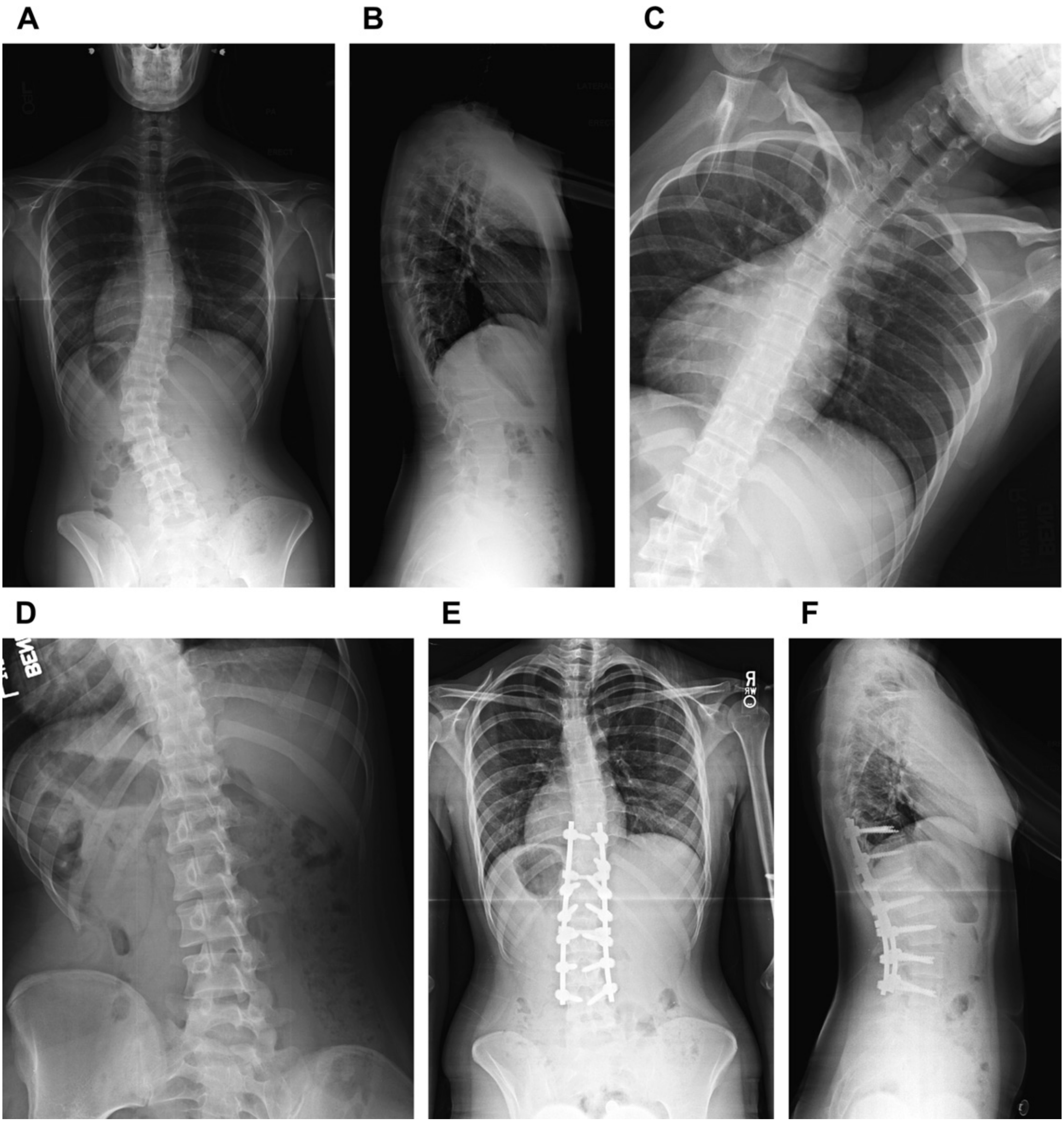

Fig. 4: Lenke 5. Preoperative standing posteroanterior (PA) (*A*) and lateral (*B*) radiographs of a 17-year-old girl with a left 45° main lumbar curve and a right 28° thoracic curve. Right (*C*) and left (*D*) bend films show that the main lumbar curve bends down to 7° and the thoracic curve bends down to 14°. One-year follow-up PA (*E*) and lateral (*F*) radiographs show correction of the main lumbar curve to 10° and correction of the thoracic curve to 6° with posterior pedicle screws from T10 to L4.

a posterior spinal fusion. The choice of the UIV is the same as for double thoracic curves, and is T2 or T3, depending on curve flexibility and shoulder height discrepancy. Selection of LIV is in accordance with the rules for double major curves.

Lenke 5: thoracolumbar/lumbar

For Lenke 5 curves (**Fig. 4**), generally, only the major thoracolumbar/lumbar curve is fused using an anterior or posterior approach. Traditionally, the anterior approach was often used because of its ability to save fusion levels compared with the posterior approach using hooks and rods.[58–64] The fusion levels for the anterior approach included only the thoracolumbar/lumbar curve from the proximal end vertebra to the distal end vertebra. With the use of pedicle screws, studies have shown that fusion levels through the posterior approach can be equivalent to those using the anterior approach, as well as the ability to achieve correction without having to violate the thoracic cavity.[65–69]

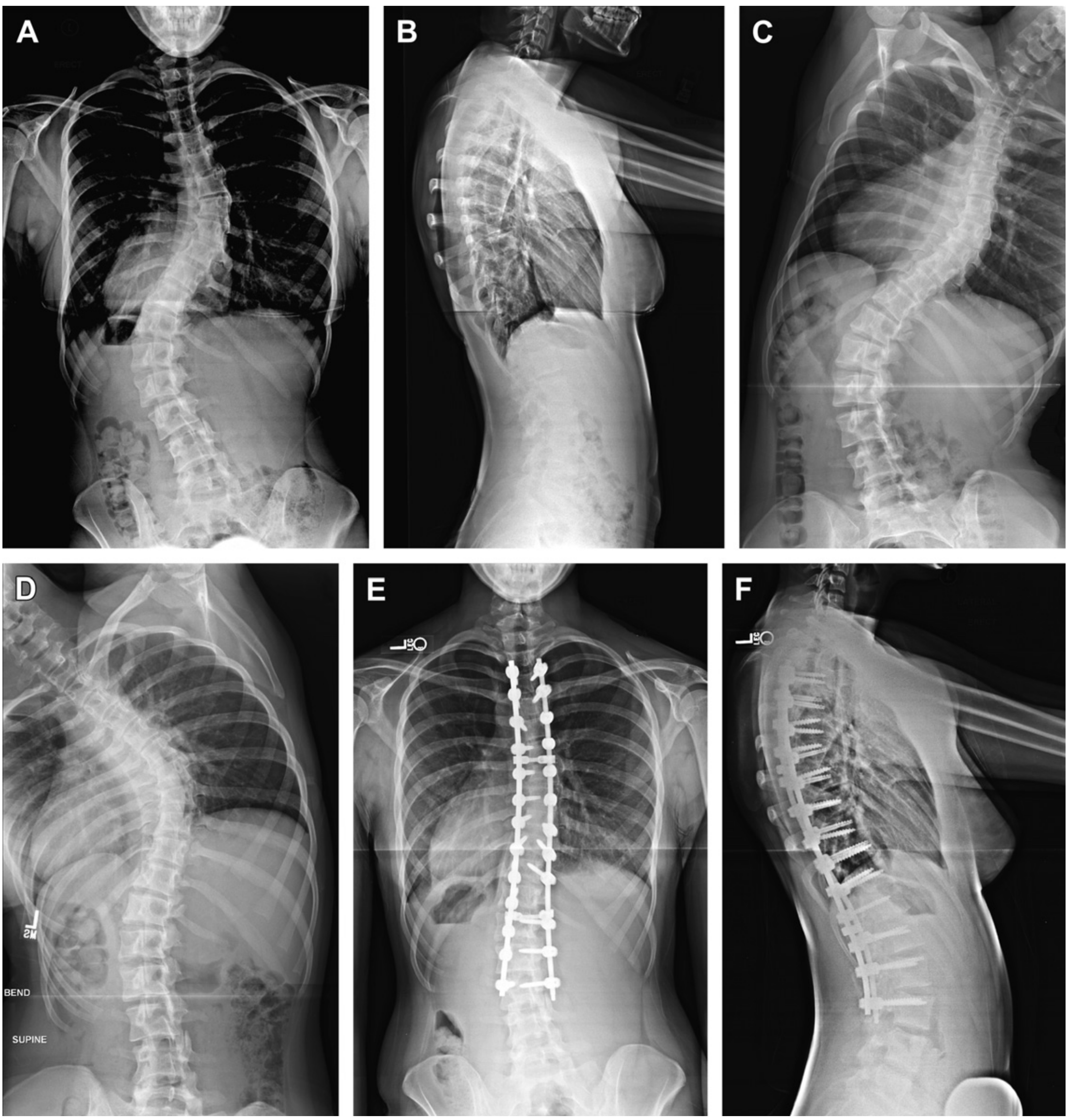

Fig. 5: Lenke 6. Preoperative standing posteroanterior (PA) (*A*) and lateral (*B*) radiographs of a 14-year-old girl with a left 52° main thoracolumbar curve and a right 42° thoracic curve. Right (*C*) and left (*D*) bend films show that the main thoracolumbar curve bends down to 27° and the thoracic curve bends down to 29°. One-month follow-up PA (*E*) and lateral (*F*) radiographs show correction of the main thoracolumbar curve to 19° and correction of the thoracic curve to 17° with posterior pedicle screws from T2-L3.

Similar to recommendations for selective thoracic fusions, for selective thoracolumbar/lumbar fusions to be successful, the ratio criteria of thoracolumbar/lumbar/main thoracic Cobb magnitude, AVT and AVR should be greater than 1.2, and the main thoracic curve should be more flexible than the thoracolumbar/lumbar curve.[55] In cases in which the main thoracic curves are not flexible, and thus have a high probability for postoperative residual curve, the UIV of the fused thoracolumbar/lumbar curve should be left tilted to achieve good balance between the fused curve and unfused main thoracic curve. A relative contraindication for a selective thoracolumbar/lumbar fusion is if a major left thoracolumbar/lumbar curve was accompanied by a depressed left shoulder, because correction of the curve would further accentuate the shoulder imbalance by pulling the left shoulder down.[55]

Lenke 6: thoracolumbar/lumbar/main thoracic

Lenke 6 curves (**Fig. 5**) can be treated similarly to double major curves, because both the major thoracolumbar/lumbar curve and the minor main thoracic curve are structural. Both curves should be included in the fusion. In choosing UIV levels, the upper limits of the main thoracic curve and shoulder alignment should be considered, similar to treating type 3 curves. Treatment guidelines for the LIV are similar to types 3, 4, and 5, in which the most proximal lumbar vertebra crossing the CSVL is used. Suk and colleagues' rules for choosing L3 or L4 using lumbar bending films are also applicable for Lenke 6 curves.[49,56]

SUMMARY

The Lenke classification is a general guideline for the operative treatment of AIS. Since the original classification was proposed, some controversies have arisen, especially for indications for selective fusions. In an era of pedicle screw use, the posterior-only approach is becoming the mainstay of treatment of all Lenke curve types. Further studies on AIS will better define the specific indications and exceptions to the Lenke guidelines to optimize treatment.

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