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The Lenke Classification System of Operative Adolescent Idiopathic Scoliosis

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Adolescent idiopathic scoliosis (AIS) constitutes the most common type of spinal deformity seen in patients between the ages of 10 and 18 years. AIS is a diagnosis of exclusion, being made after the patient has been evaluated for underlying syndromic, congenital, neurologic, or muscular etiologies of his or her deformity. The prevalence of AIS is estimated at approximately 2% to 3% of the population. The prevalence decreases dramatically with increasing curve severity, however. The prevalence of a 40° AIS curve is approximately 0.1%. AIS is much more common in girls than in boys, with a ratio of 9:1 in curves that are in the operative range of at least 40° to 50°.

Treatment of AIS consists of observation, bracing, or surgery. Observation is indicated for curves less than 25° in skeletally immature patients and for curves up to 40° in skeletally mature patients. Bracing is recommended for skeletally immature patients with curves between 25° and 40° to 45°. Surgery is considered for skeletally immature patients with progressive curves greater than 40° and for skeletally mature patients with progressive curves greater than 45° to 50°.

Lenke classification system

A new treatment-directed classification system of AIS was published in 2001 by Lenke and colleagues [1]. This classification system of operative AIS had six goals, to (1) be comprehensive for classification of all curve types, (2) be two dimensional to include analysis of the coronal and sagittal planes, (3) be treatment based to help guide operative decision making, (4) have good to excellent inter- and intraobserver reliability, (5) have specific objective criteria to help separate curve types, and (6) be practical and easily understood and usable for scoliosis surgeons and trainees.

The radiographic analysis required for the Lenke classification system of AIS begins with upright coronal, sagittal, and right and left side-bending flexibility films. On the upright coronal radiograph, the proximal thoracic (PT), main thoracic (MT), and thoracolumbar/lumbar (TL/L) Cobb measurements are obtained. The major curve is the region with the largest Cobb measurement, and the other two regions are noted as minor curves.

In the sagittal plane, T2-T5, T5-T12, and T10-L2 regional sagittal Cobb measurements are obtained as well. In this operative classification system, the major curve is always included in the fusion. Thus, the minor curves must be carefully evaluated to determine whether they should also be included in the fusion of the major curve. To assist in this determination, minor curve structural criteria are integral to this classification system. In the coronal plane, residual side-bending curves of 25° or greater in each of the three regions (PT, MT, and TL/L) as well as sagittal hyperkyphosis of +20° or greater in the T2-T5 or T10-L2 region signify the minor curves as structural.

Thus, based on whether the three regions are structural or nonstructural, a template of six curve types can be constructed (Fig. 1). A type 1 MT curve only has the MT region as major and structural. A type 2 double thoracic (DT) curve has the MT region as the major curve and the PT region as a structural minor curve. A type 3 or double major (DM) curve has the MT region as the major

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CURVE TYPE	PT	MT	TL/L	DESCRIPTION
1	NS	S*	NS	Main Thoracic (MT)
2	S	S*	NS	Double Thoracic (DT)
3	NS	S*	S	Double Major (DM)
4	S	S*	S*	Triple Major (TM)
5	NS	NS	S*	Thoracolumbar/Lumbar (TL/L)
6	NS	S	S*	Thoracolumbar/Lumbar-Main Thoracic (TL/L-MT)

S = Structural
NS = Non-Structural
*Major (largest curve)

Fig. 1. Six curve types are described by means of the Lenke classification system, based on the structural characteristics of the PT, MT, and TL/L regions.

curve, whereas the TL/L region is a structural minor curve. For a type 4 triple major (TM) curve, the MT or TL/L region is the major curve, whereas the other two regions are structural minor curves. The type 5 TL/L curve has the major curve in the TL/L region, with the other two regions being nonstructural. Finally, the type 6 TL/L-MT curve has the TL/L region as the major curve, whereas the MT region is a structural minor curve.

Two modifiers are added to this system to assist further with differentiating various curve patterns. A lumbar spine modifier A, B, or C is added, based on the position of the center sacral vertical line (CSVL) to the apex of the TL/L curve (Fig. 2). For lumbar modifier A, the CSVL intersects the apex of the lumbar spine between the pedicles. For lumbar modifier B, the CSVL touches the apical pedicle(s) of the lumbar curve. For lumbar modifier C, the CSVL falls medial to the apical pedicle(s) and vertebral body(ies) of the TL/L curve. Thus, as one goes from an A to a B to a C lumbar modifier, there is increasing lateral translation of the apex of the TL/L curve. Finally, a sagittal thoracic modifier is added, based on the T5-T12 sagittal Cobb measurement. A minus (−) or hypokyphotic modifier is added when the T5-T12 sagittal Cobb measurement is less than +10°, an N or normal kyphotic modifier is added when the T5-T12 sagittal Cobb measurement is between +10° and +40°, and a plus (+) or hyperkyphotic modifier is added when the T5-T12 sagittal Cobb measurement is greater than +40°. Thus, the triad classification system combines the curve type (1–6) with the lumbar spine modifier (A, B, or C), along with the sagittal thoracic modifier (−, N, or +) to create the complete classification system (eg, 1A−).

Although this radiographic classification system is fairly descriptive because of the thorough radiographic analysis required, there are other clinical factors that help to determine the specific fusion levels to be performed on operative patients with AIS [2]. These include the level of skeletal maturity, preoperative shoulder alignment, thoracic and lumbar prominences, and truncal balance, among others. Thus, this classification system must be combined with these various clinical factors and prior operative experience to help guide the surgeon to appropriate fusion level selection in his or her operative patients with AIS.

Specific curve types

Curve type 1

A type 1 MT curve pattern has the major curve in the MT region, with the PT and TL/L regions being nonstructural minor curves. Thus, instrumentation and fusion of the MT region alone is recommended. This can be accomplished through a posterior spinal fusion (PSF) or anterior spinal fusion (ASF). In the past decade, most of these fusions at the author's institution have been performed posteriorly with pedicle screw constructs [3,4]. The upper instrumented vertebra (UIV) is either T3, T4, or T5, whereas the lowest

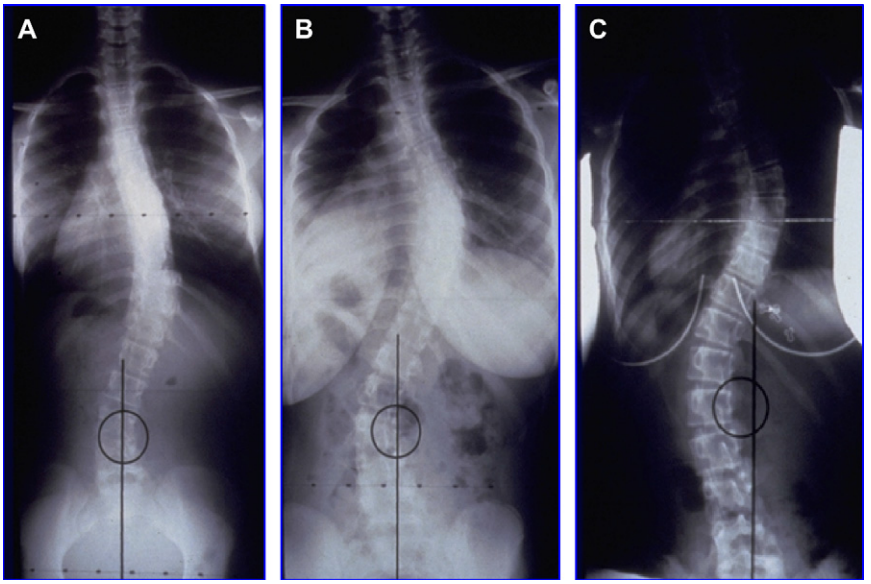

Fig. 2. Lumbar spine modifier positions *A*, *B*, and *C* are depicted, based on the deviation of the CSVL from the apex of the lumbar curve. As one progresses from an *A* to a *B* to a *C* modifier, there is increasing translation of the lumbar apex to the CSVL.

instrumented vertebra (LIV) varies considerably, based on many radiographic factors, including the lumbar spine modifier. For lumbar modifier A curve patterns, the LIV is usually selected as the most cephalad vertebra in the TL/L region that is at least intersected by the CSVL on the upright coronal radiograph. This is usually one level below the lower end vertebra (LEV) of the MT curve and one or two levels above the true stable vertebra. Correction techniques include cantilever, in situ contouring, and appropriate compression and distraction forces applied in an attempt to maximally translate the apex and horizontalize the LIV. Correction techniques are similar for type 1B curve patterns; however, the author usually recommends keeping a slight bit of residual tilt to the LIV to accommodate the slight lumbar apical translation seen in a B modifier lumbar curve pattern.

The type 1C curve pattern is, at times, highly controversial. Even though the TL/L region completely deviates from the CSVL at the apex, the TL/L curve side bends less than 25° and lacks a true junctional kyphosis. Thus, a selective thoracic fusion is recommended and can be performed by means of an ASF or a PSF [5]. An ASF down to the LEV of the MT curve is certainly an acceptable treatment method, especially if the sagittal plane demonstrates a "−" or hypokyphotic sagittal modifier and the preoperative pulmonary function tests show acceptable values to allow an open thoracotomy or an endoscopic approach [6,7]. Posterior treatment using pedicle screw constructs usually involves fusion down to the true stable vertebra at T11 (rarely), T12, or L1. It is important to analyze the sagittal plane to make sure that any slight junctional kyphosis is included in the PSF regardless of where the coronal stable vertebra falls. Selective thoracic fusions for a type 1C curve pattern are important to maximize lumbar spine motion and can be accomplished successfully with thorough evaluation and appropriate operative techniques, including under correction of the MT curve to allow harmonious balance with the unfused lumbar spine below. The author usually attempts to correct the thoracic curve to a degree that matches the preoperative lumbar supine TL/L Cobb measurement. It is also important to leave a fair amount of residual tilt to the LIV to accommodate the unfused lumbar spine below. The author usually tries to leave approximately 50% of the tilt remaining from the preoperative upright coronal radiograph. Using careful preoperative analysis and intraoperative techniques, successful selective thoracic fusions can be performed with a high

level of patient satisfaction and with minimal risk of decompensation [8,9].

Curve type 2

A type 2 DT curve has the MT region as a major curve, along with a structural PT region. Thus, treatment includes a PSF of the PT and MT regions. The UIV begins typically at T2, or sometimes at T3, and the LIV can be chosen in a similar fashion to what was described for the treatment of type 1 MT curves. In this regard, the LIV is chosen and corrected, based on the lumbar spine modifier A, B, or C (Fig. 3).

With the structural PT region seen radiographically, it is extremely important to pay attention to the clinical shoulder balance as well. Often, the left shoulder is elevated, correlating with

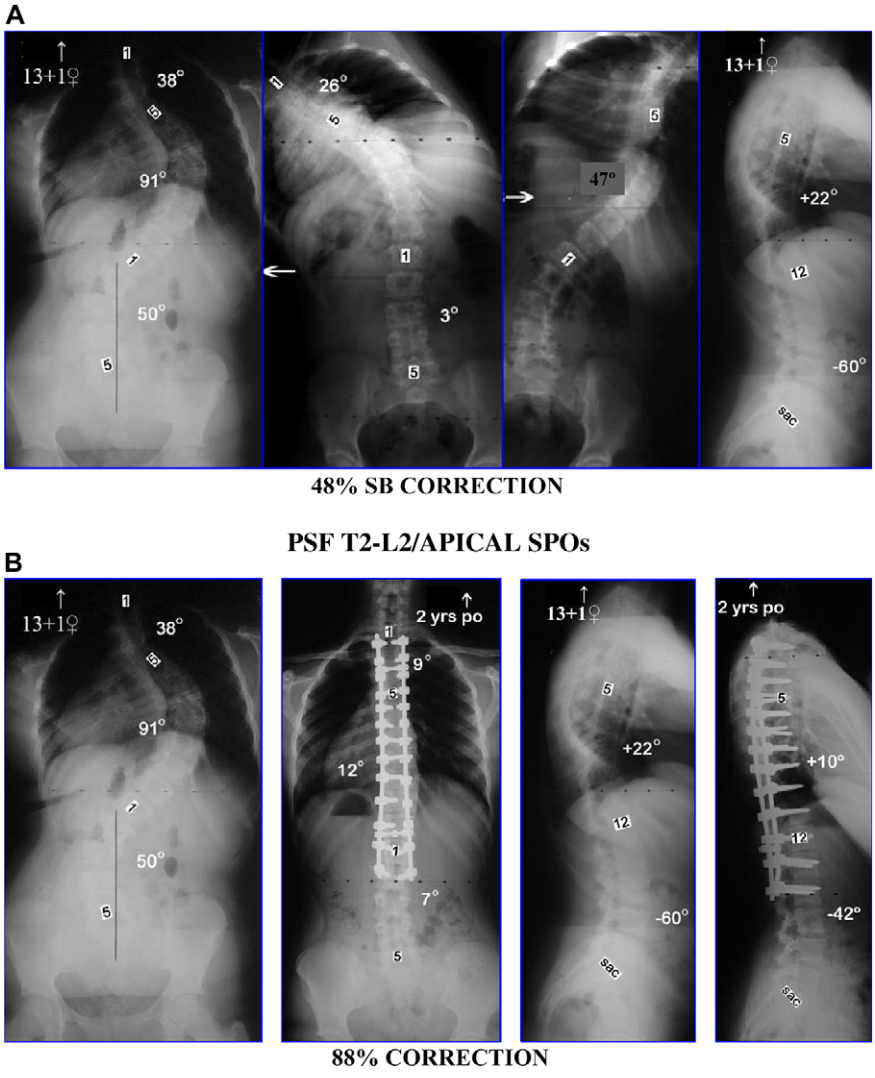

Fig. 3. (*A*) A 13 + 1-year-old female patient presented with a 38° PT, 91° MT, and 50° TL/L AIS. Her left side-bending (SB) showed a structural PT region at 26° and a nonstructural lumbar region side bending to 3°. Her sagittal modifier was normal at +22° of kyphosis from T5 to T12, and her lumbar modifier was a B. Thus, her complete curve classification is 2BN. (*B*) She underwent posterior instrumentation and a fusion with segmental pedicle screw fixation from T2 to L2, with excellent coronal and sagittal realignment noted 2 years after surgery. SPOs, subtraction pedical osteotomies. (*C*) Her pre- and postoperative clinical photographs demonstrate her excellent truncal realignment and rib hump improvement after surgery.

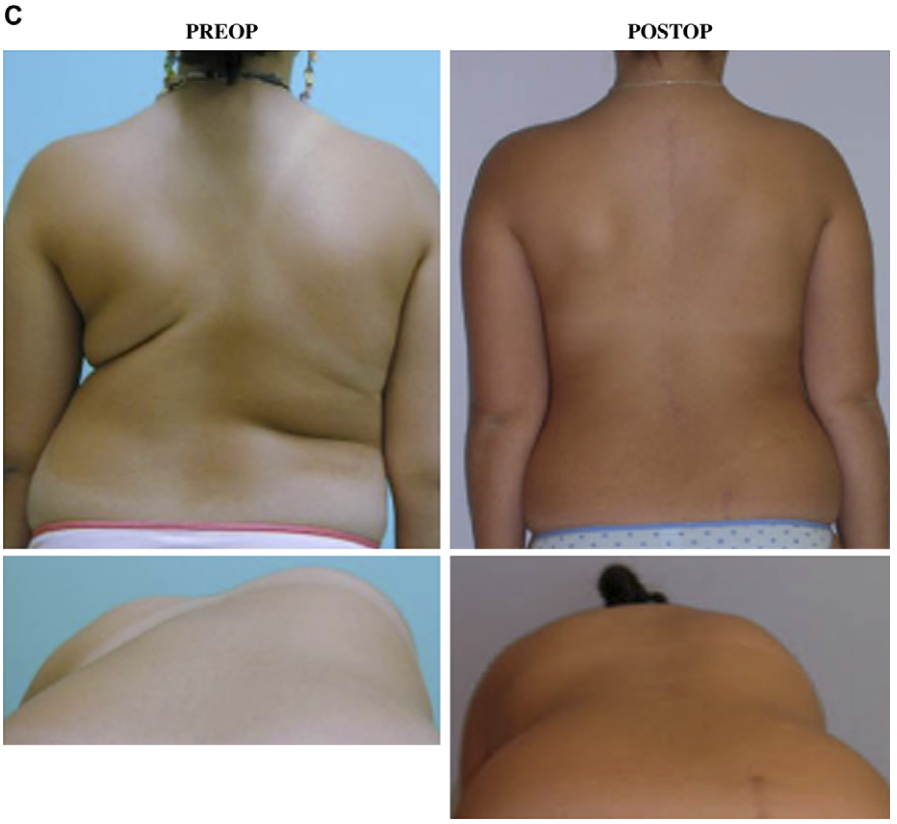

Fig. 3 (*continued*)

a structural left-sided PT region for a right MT major curve [10]. In that scenario, fusion up to T2 is required, with convex compression forces applied on the left side of the PT curve and concave distraction forces applied on the right side of the PT curve to rebalance the shoulders. When the shoulders are level clinically for a type 2 DT curve pattern, fusion is still required up to T2 or T3 with similar correction forces applied to maintain shoulder balance. In the rare circumstance that the right shoulder is high for a type 2 curve pattern, the fusion still needs to be extended up to T2 or T3, usually to rebalance the shoulders with correction of the MT curve. Rarely, the fusion may start as low as T4 or T5 and leave the structural PT curve unfused in this scenario, but one must be careful that the left shoulder does not become elevated after surgery [11].

Curve type 3

A type 3 DM curve consists of a major MT region with a structural TL/L region. Thus, operative treatment requires instrumentation and fusion of the MT and TL/L regions through a PSF approach. The UIV is similar to that of a type 1 curve, beginning at T3, T4, or T5, based on radiographic and clinical factors of the nonstructural PT curve and shoulder alignment. The LIV usually needs to extend to L3 or L4. If the apex of the TL/L curve is L2 or caudad, the L3-4 disc is convex or open on the convexity of the TL/L curve, and L4 is a grade I Nash-Moe rotation or greater, the instrumentation and fusion need to extend to L4. Conversely, if the apex is the L1-2 disc or cephalad, the L3-4 disc is neutral or closed on the convex side of the TL/L curve, and L3 is a grade 1.5 or less Nash-Moe rotation [12], L3 can usually be selected as the LIV.

Most type 3 DM curves are associated with a lumbar C modifier. Those curves that have a lumbar A or B modifier usually have an extremely large MT Cobb measurement that makes the residual TL/L return curve structural on side-bending. Alternatively, a junctional TL kyphosis

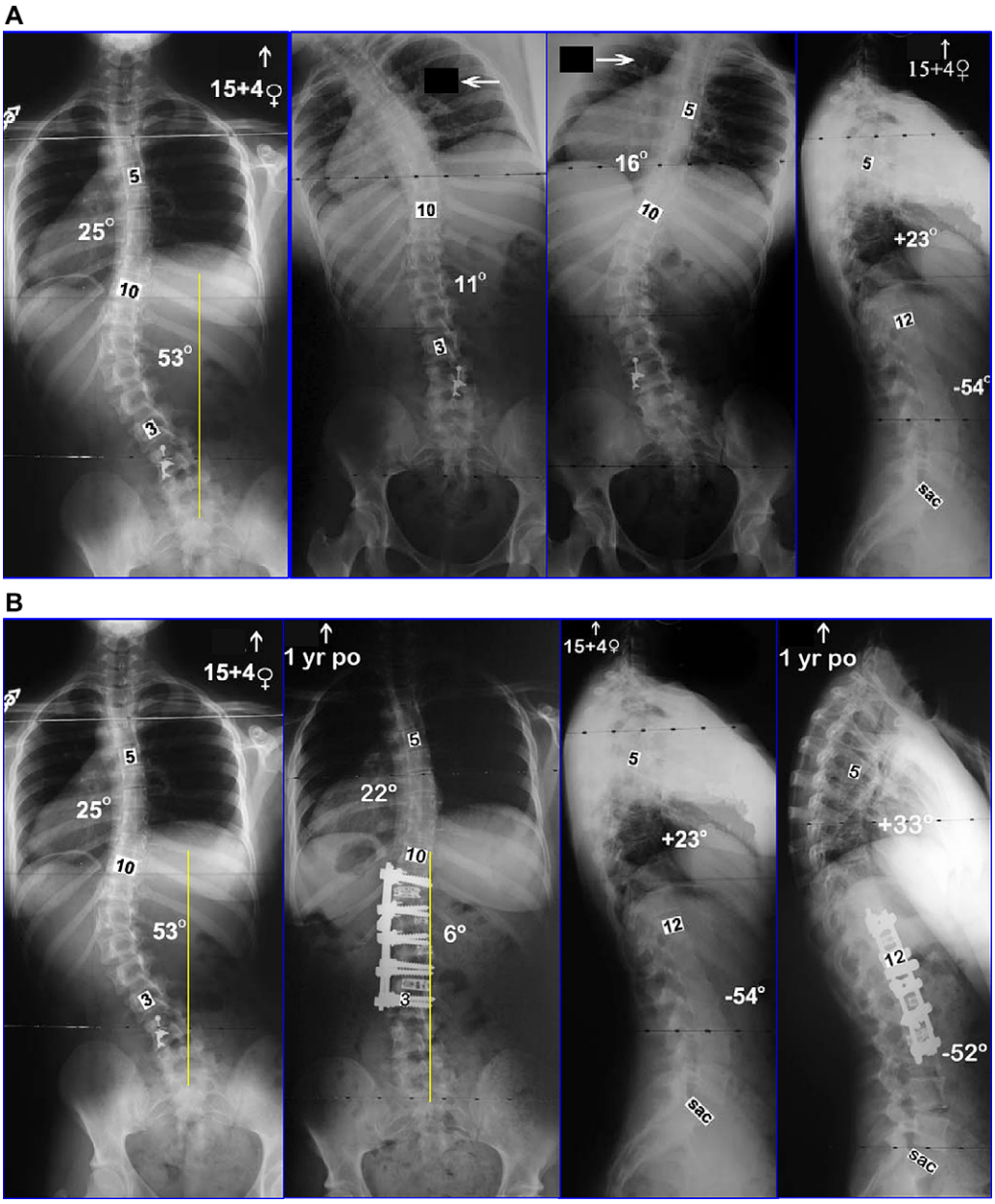

Fig. 4. (*A*) A 15 + 4-year-old female patient had 25° MT and 53° TL/L scoliosis, with the MT region being the non-structural side bending to 16°. She had a C lumbar modifier and a normal sagittal plane modifier. Thus, her complete curve classification is 5CN. (*B*) She underwent anterior instrumentation and a fusion from T11 to L3 with a dual-rod construct and intervertebral cages for structural support. One year after surgery, she has excellent coronal and sagittal alignment and balance to her spine. (*C*) Her pre- and postoperative clinical photographs demonstrate her nice truncal correction after her ASF.

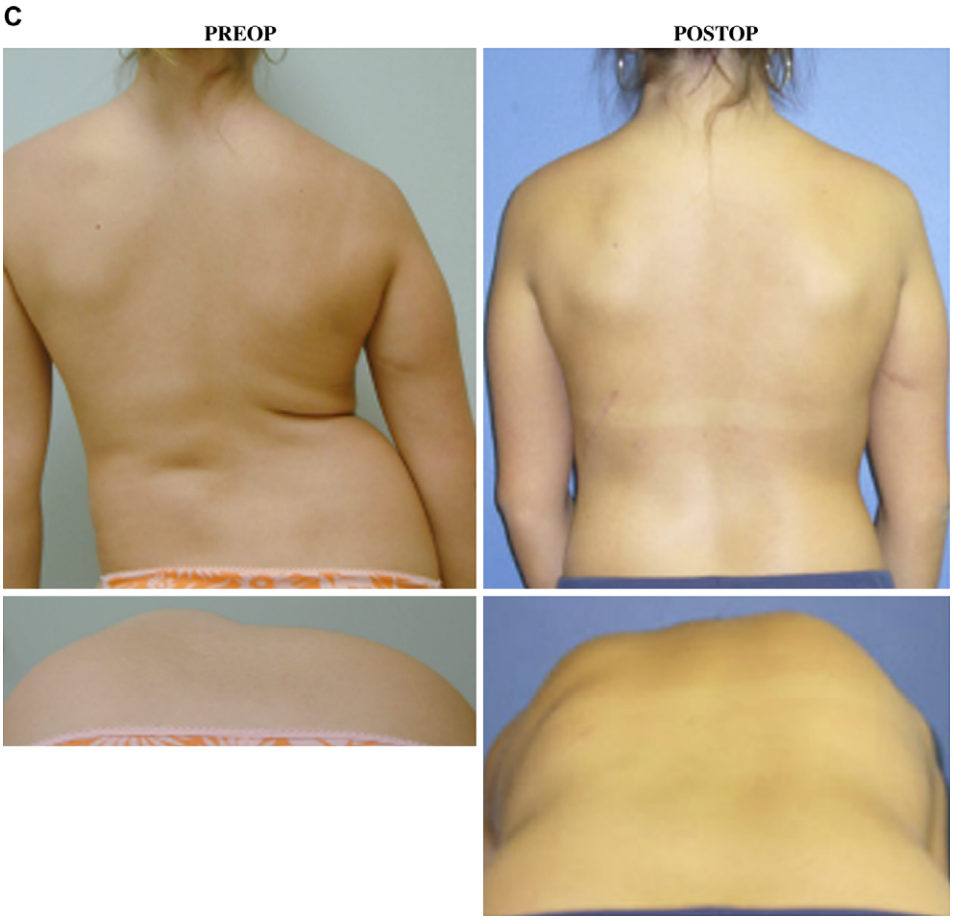

Fig. 4 (*continued*)

of +20° or greater creates a type 3 DM curve pattern even when the coronal flexibility would predict a nonstructural TL/L region. A special circumstance exists in a 3C pattern, whereby one may consider a selective thoracic fusion. In this scenario, the MT region is much more structural than the TL/L region. Ratio criteria comparing MT and TL/L Cobb measurements, apical vertebral translation (AVT), and apical vertebral rotation (AVR) demonstrate ratios of (MT:TL/L) or greater [8]. Also, if the clinical examination correlates with the much more structural and larger MT region, a selection thoracic fusion may be considered in this special circumstance.

Curve type 4

A type 4 TM curve has the major curve in the MT or TL/L region, with the other two regions, including the PT region, as structural minor curves. Thus, all three regions—PT, MT, and TL/L—need to be included in the instrumentation and fusion by means of a PSF. The UIV is selected in accordance with the rules for the type 2 DT curve pattern, whereas the LIV is selected in accordance with the rules for the type 3 DM curve pattern. Thus, this rare curve pattern usually requires extremely long instrumentation and fusion from T2 or T3 down to L3 or L4 [13,14].

Curve type 5

A type 5 TL/L curve pattern has the major curve in the TL/L region, with nonstructural PT and MT regions. Thus, this single curve pattern can be treated with an isolated ASF or PSF of the TL/L region. Traditionally, the author has treated these curves anteriorly with a single- or, more recently, dual-rod anterior instrumentation construct (Fig. 4) [15]. The UIV is the upper end

vertebra (UEV) of the TL/L curve, whereas the LIV is the LEV of the TL/L curve. Alternatively, a PSF may be performed of the isolated TL/L region as well. Often, the UIV is one or two levels above the UEV of the curve, whereas the LIV is the LEV or one level below the LEV of the TL/L curve. Either approach is a viable alternative currently, with a multicenter prospective study required to differentiate whether one approach is superior to the other [16].

Curve type 6

A type 6 TL/L-MT curve has a major curve in the TL/L region, with the MT region being a structural minor curve. Both regions are treated with a PSF of the MT and TL/L regions. Thus, this curve pattern is often treated in an identical fashion as a type 3 DM curve. Rarely, a selective TL/L fusion is performed on the basis of structural criteria comparing the TL/L with the MT region. Thus, with increased Cobb measurements, AVT, and AVR of the TL/L versus the MT region, an isolated TL/L selective fusion may be performed anteriorly or posteriorly.

Summary

The operative treatment of AIS is still somewhat controversial regarding selection of the appropriate regions to fuse and selection of the specific UIV and LIV [14]. The Lenke classification system helps to determine the appropriate regions of the spine to be fused. The fused regions include the major curve and any structural minor curves by means of the criteria listed previously. After this, the approach, anteriorly or, more commonly, posteriorly, and the actual UIV and LIV are selected by various rules, some of which are quite idiosyncratic. Ultimately, multicenter studies evaluating large numbers of similar curve patterns treated differently should help sort out the best treatment for each particular curve pattern, thus optimizing surgical treatment for patients with AIS.

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