INTRODUCTION

Scoliosis, classically viewed as a deformity in the frontal plane, is a three dimensional deformity of the spine comprising coronal plane curvature and axial rotation with maximal translation and rotation occurring at the apex. The spine should normally be straight in the frontal plane, whilst in the sagittal plane a series of curvatures confer the natural stable shape of the spine. The thoracic spine exhibits kyphosis averaging 30 degrees (range 10 to 40 degrees) as measured from the superior endplate of T5 to the inferior endplate of T12. The lumbar spine should be lordotic averaging 55 degrees (range 35 to 80 degrees) as measured from the inferior endplate of T12 to the superior endplate of S1. The junctional region of the spine between T10 and L2 should be relatively neutral or slightly lordotic.

Scoliosis is typically classified by aetiology, and can be broadly categorized as idiopathic, neuromuscular, syndromic and congenital. By far the most common type is idiopathic comprising 80% of patients with scoliosis. Idiopathic scoliosis is defined as a coronal plane curvature of the spine for which no aetiology can be identified. Idiopathic scoliosis is further subclassified based on the age of diagnosis. The descriptions as recommended by the Scoliosis Research Society (SRS) are as follows: Infantile (0 to 2+11 years); Juvenile (3 to 9+11 years); Adolescent (10 to 17+11 years); Adult from 18 years onwards.

CURVE DESCRIPTION

Classification within medicine is important to facilitate the recognition, description, treatment, and the comparison of treatments of a condition. A number of schemes have been designed to describe the patterns of curvature occurring in idiopathic scoliosis. In order to describe a scoliotic spine in a repeatable and reliable manner the position and magnitude of the curvature or curvatures must be measured in a standard fashion. In order to do this certain features of the curve must be identified. These include the apex or apices of the curve(s), and the end vertebrae of each section of the curve. The apex defines the center of the curve and is the most laterally displaced and most horizontal vertebra or intervertebral disc (Figure 1B). The end vertebrae describe the proximal and distal extents of a curve and are defined as those that tilt maximally from the horizontal into the concavity of the curvature. The degree of tilt between the end vertebrae defines the maximal coronal deviation of the curve, defined as the Cobb angle. The Cobb angle is measured from a standing posteroanterior long cassette radiograph. The end vertebrae of the curve are first identified, and the superior and inferior endplates of the cranial and caudal vertebrae respectively are highlighted. Perpendicular lines to these endplates are constructed and intersected, and the angle subtended by this intersection denotes the Cobb angle of the curve so measured (Figure 1A). This must be repeated for all the curves present.

More recently the importance of the sagittal profile of the scoliotic spine has been recognised and this can be identified on the long cassette lateral standing radiograph. Cobb angles are measured for the thoracic spine (T5 to T12), junctional region (T10 to L2) and the lumbar spine (T12 to S1). The fifth thoracic vertebra is selected by convention as the apex of the curve so measured (Figure 1A). This must be repeated for the thoracic spine, as commonly the first thoracic segment is poorly visualized (Figure 1C).

CLASSIFICATION SCHEMES

In 1983, King et al. presented their system for classifying thoracic adolescent idiopathic scoliosis (AIS). The scheme offered five different curve types enabling the evaluation and comparison of patients and outcomes. The system also provided an algorithm through which surgeons could identify the curves and vertebral levels for arthrodesis. The King system remained the principal classification system in AIS for nearly 20 years. Recently however various limitations of the scheme have been highlighted. First, the system is by no means comprehensive with the description only of thoracic curves. As a result there is no application to thoracolumbar, lumbar, double or triple major curves. The original clinical series upon which the King classification was based were all treated by the Harrington rod technique. This technique only addresses the coronal plane deformity and as already noted scoliosis is a triplanar deformity also requiring analysis of the sagittal plane. With the advent of segmental spinal instrumentation, triplanar correction has become possible and the King classification does not allow for assessment of this. When the classification system was scrutinized by two independent groups, King only scored fair-to-poor on inter and intraobserver validity,
reliability and reproducibility. As a result of these shortcomings, Lenke et al. designed a new classification system for the operative management of AIS. The new scheme was designed to be:
1. Fully inclusive of all curve types.
2. Two-dimensional with more emphasis on sagittal plane alignment.
3. Treatment based, enabling arthrodesis of necessary curves and allowing selective fusion when appropriate.
4. Objective, using strict criteria to differentiate curve patterns.
5. Reliable, with good-to-excellent inter and intraobserver reproducibility.
6. Easily understood, practical and clinically relevant.

LENKE AIS CLASSIFICATION SYSTEM

The Lenke classification is a modular system comprising three components. The curve type, the lumbar spine and thoracic sagittal modifiers. Once each component is assessed separately, a classification triad is created (Figure 2). In order to obtain the components of the triad, four long cassette radiographs are required: standing posteroanterior and lateral, and right and left supine bending films. The first stage of classification involves the division of the spinal column into three regions: 1. Proximal thoracic (PT); apex at T3, T4 or T5; 2. Main thoracic (MT); apex between T6 and the T11-12 disc; 3. Thoracolumbar/Lumbar (TL/L); apex at T12 or L1 for thoracolumbar curves, and between the L1-2 disc and L4 for lumbar curves.

A Cobb measurement is obtained for each of the three regions, and the curves are classified as major or minor with the largest numerical curve being designated the major curve. The remaining minor curves are then classified as structural or non-structural dependent on the curve flexibility and sagittal alignment. A curve is denoted as structural if it exhibits coronal plane rigidity of ≥ 25º on side bending, and/or kyphosis ≥ 20º on lateral radiographs. The three spinal regions with reference to sagittal angulations are as follows: PT (T2-5), MT (T5-12) and TL/L (T10-L2). When the major and minor curve patterns are combined (Chart 1, Figures 3 e 4) six curve types emerge and can be defined as:
1. Type 1 Major thoracic (MT)
2. Type 2 Double thoracic (DT)
3. Type 3 Double major (DM)
4. Type 4 Triple major (TM)
5. Type 5 Thoracolumbar/Lumbar (TL/L)
6. Type 6 Thoracolumbar/Lumbar-Main thoracic (TL/L-MT)

---

<table>
<thead>
<tr>
<th>Type</th>
<th>Proximal Thoracic</th>
<th>Main Thoracic</th>
<th>Thoracolumbar/Lumbar</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Non-Structural</td>
<td>Structural (Major)*</td>
<td>Non-Structural</td>
<td>Main Thoracic (MT)</td>
</tr>
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<td>Structural (Major)*</td>
<td>Non-Structural</td>
<td>Double Thoracic (DT)</td>
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<td>3</td>
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<td>Structural (Major)*</td>
<td>Structural</td>
<td>Double Major (DM)</td>
</tr>
<tr>
<td>4</td>
<td>Structural</td>
<td>Structural (Major)*</td>
<td>Structural</td>
<td>Triple Major (TM)*</td>
</tr>
<tr>
<td>5</td>
<td>Non-Structural</td>
<td>Non-Structural</td>
<td>Structural (Major)*</td>
<td>Thoracolumbar/Lumbar (TL/L)</td>
</tr>
<tr>
<td>6</td>
<td>Non-Structural</td>
<td>Structural</td>
<td>Structural (Major)*</td>
<td>Thoracolumbar/Lumbar-Main Thoracic (TL/L-MT)</td>
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</tbody>
</table>

**STRUCTURAL CRITERIA**

<table>
<thead>
<tr>
<th>Major Curves</th>
<th>Minor Curves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal Thoracic</td>
<td>Side Bending Cobb ≥ 25º</td>
</tr>
<tr>
<td>Main Thoracic</td>
<td>Side Bending Cobb ≥ 25º</td>
</tr>
<tr>
<td>Thoracolumbar/Lumbar</td>
<td>Side Bending Cobb ≥ 25º</td>
</tr>
</tbody>
</table>

**LOCATION OF APEX**

<table>
<thead>
<tr>
<th>CURVE APEX</th>
<th>CURVE Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thoracic</td>
<td>T2-T11/12 Disc</td>
</tr>
<tr>
<td>Thoracolumbar</td>
<td>T12-L</td>
</tr>
<tr>
<td>Thoracolumbar/Lumbar</td>
<td>L1-2 Disc/L4</td>
</tr>
</tbody>
</table>

**Modifiers**

<table>
<thead>
<tr>
<th>Modifier</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>CSVL between pedicles</td>
</tr>
<tr>
<td>B</td>
<td>CSVL touches apical body</td>
</tr>
<tr>
<td>C</td>
<td>CSVL completely medial</td>
</tr>
</tbody>
</table>

Figure 2

In curve types 1 to 3 the MT curve is major, and in types 5 and 6 the major curve is the TL/L. In the type 4 curve pattern, either the MT or the TL/L curves can be the major. On the basis of this classification arthrodesis should only include the major and structural minor curves. In order to incorporate the degree of lumbar coronal plane deformity a modifier is then added to the main curve type. A line is drawn vertically through the midpoint of S1 on the standing PA radiograph. This is the Center Sacral Vertical Line (CSVL). This is then related to the apex of the lumbar curvature on the same film. If the apex is a disc the assessment is based upon the vertebrae immediately above and below the apical disc. If the CSVL falls between the pedicles of the apical vertebra then Lumbar modifier A is assigned. When the CSVL falls above the pedicles and below the vertebral body wall in the concavity then B modifier is assigned. Finally, if the CSVL falls entirely to the medial of the concavity of the apical vertebra then C modifier applies. In the situation when distinction between A and B modifiers or B and C modifiers cannot be determined, then modifier B is assigned (Figure 5).

The third and final component of the classification requires the assignment of a sagittal thoracic modifier. This

<table>
<thead>
<tr>
<th>Curve type</th>
<th>Description</th>
<th>Proximal Thoracic</th>
<th>Main Thoracic</th>
<th>Thoracolumbar/Lumbar</th>
<th>Structural Region of each Curve Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main Thoracic</td>
<td>Nonstructural</td>
<td>Structural (major)</td>
<td>Nonstructural</td>
<td>Main Thoracic, Proximal Thoracic, Thoracolumbar/Lumbar</td>
</tr>
<tr>
<td>2</td>
<td>Double Thoracic</td>
<td>Structural</td>
<td>Structural (major)</td>
<td>Nonstructural</td>
<td>Main Thoracic, Main Thoracic, Thoracolumbar/Lumbar</td>
</tr>
<tr>
<td>3</td>
<td>Double Major</td>
<td>Nonstructural</td>
<td>Structural (major)</td>
<td>Structural</td>
<td>Thoracolumbar/Lumbar, Main Thoracic, Thoracolumbar/Lumbar</td>
</tr>
<tr>
<td>4</td>
<td>Triple Major</td>
<td>Structural</td>
<td>Structural (major)</td>
<td>Structural (major)</td>
<td>Thoracolumbar/Lumbar, Thoracolumbar/Lumbar, Main Thoracic</td>
</tr>
<tr>
<td>5</td>
<td>Thoracolumbar/Lumbar</td>
<td>Nonstructural</td>
<td>Structural (major)</td>
<td>Structural (major)</td>
<td>Thoracolumbar/Lumbar, Thoracolumbar/Lumbar, Main Thoracic</td>
</tr>
<tr>
<td>6</td>
<td>Thoracolumbar/Lumbar-Main Thoracic</td>
<td>Structural</td>
<td>Structural (major)</td>
<td>Structural (major)</td>
<td>Main Thoracic, Thoracolumbar/Lumbar, Thoracolumbar/Lumbar, Main Thoracic</td>
</tr>
</tbody>
</table>

*A structural proximal thoracic curve has a Cobb angle of $\geq 25^\circ$ on side-bending radiographs and/or Kyphosis between the second and the fifth thoracic level of at least $+20^\circ$. A structural main thoracic curve has a Cobb angle of $\geq 25^\circ$ on side-bending radiographs and/or Kyphosis between second and the fifth thoracic level of at least $+20^\circ$. A structural thoracolumbar/lumbar curve has a Cobb angle of $\geq 25^\circ$ on side-bending radiographs and/or Kyphosis between the thoracic and the second lumbar level of at least $+20^\circ$. Either the main thoracic or the thoracolumbar/lumbar curve can be the major curve.

is based upon the Cobb measurement of the T5-12 segment of the spine on the lateral radiograph. Measurements of between +10º and +40º are assigned the normal (N) thoracic modifier. Hypokyphotic thoracic spines with Cobb angulation of <10º are assigned the minus (-) modifier, while hyperkyphosis >40º assigns a plus (+) modifier (Figure 6).

The triad that is the Lenke classification can now be constructed for any scoliosis curve, with the curve (Chart 2) type (1-6), the lumbar modifier (A, B, C) and the thoracic modifier (-, N, +) creating the final classification (e.g. 1AN, Figure 2). These combinations result in 42 different classifications and not the 54 as would be expected based on all possible combinations. This is because all surgically relevant Type 5 and 6 curves (TL/L, TL/L-MT) carry the C lumbar modifier. Numerically Type 1 (MT) account for 51% of operative cases, with Types 4 and 6 comprising only 3% each. Overall 60% of operative cases are made up of five classes of curve 1AN, 2AN, 1BN, 5CN and 1CN. Lumbar modifier A is the most prevalent (41%) followed by B (37%). Normal thoracic kyphosis (N) accounts for 75% of all thoracic modifiers.

As noted, reliability and reproducibility are important characteristics of a classification system, and the Lenke system has shown good-to-excellent inter and intraobserver reliability between the developers and within an independent group of Scoliosis Research Society surgeons. This compares very favorably with the fair-to-poor reliability of the King system as shown by the same researchers.

CHART 2 - Classification Sequence
1. Obtain standing posteroanterior, lateral, right and left supine side bending radiographs
2. Divide spinal column into three regions, PT, MT, TL/L
3. Measure Cobb angle for each curve on standing PA, lateral and bending films
4. Identify major curve(s), designate minor curve(s) structural or not (Table 1)
5. Denote curve type
6. Create CSVL on standing PA film
7. Designate Lumbar spine modifier
8. Designate sagittal thoracic modifier

TABLE 1 - Identify major curve(s), designate minor curve(s) structural or not

<table>
<thead>
<tr>
<th>Coronal S.B.</th>
<th>Sagittal</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT ≥25º</td>
<td>≥+20º(T2-T5)</td>
</tr>
<tr>
<td>MT ≥25º</td>
<td>≥+20º(T10-L2)</td>
</tr>
<tr>
<td>TL/L ≥25º</td>
<td>≥+20º(T10-L2)</td>
</tr>
</tbody>
</table>

ARTHRODESIS ACCORDING TO CURVE TYPE

Treatment direction was a main goal of the Lenke classification, enabling decision-making on structural curves to be
instrumented\textsuperscript{15}. In a retrospective analysis of 606 patients treated before the establishment of the Lenke classification, approximately 90% of cases followed the guidelines subsequently advocated by the system.

The Lenke classification now allows operative treatment to be based upon curve type with due consideration of the associated modifiers.

**Type 1: Main Thoracic Curves**
Type 1 curves are the most prevalent curve pattern\textsuperscript{17} and treatment requires fusion of the main thoracic (MT) curve. This can be achieved either anteriorly or posteriorly or both simultaneously. Posterior instrumentation has been the mainstay of surgical management for four decades, and can be used for the arthrodesis of Main Thoracic curves independent of sagittal or thoracic modifiers. Posterior surgery carries several advantages over the anterior approach, including patients with a hyperkyphotic (+) sagittal modifier, patients with a large body habitus who may benefit from double rod posterior instrumentation, patients with abnormal pulmonary function in whom thoracic surgery may be inappropriate, and finally for surgeons who are more familiar with the posterior approach to the thoracic spine\textsuperscript{9, 18-23} (Figure 7).

Patients with Type 1 curves who may benefit from an anterior approach include those who exhibit a hypokyphotic (-) thoracic modifier, those with a C lumbar modifier to optimize spontaneous lumbar correction, skeletally immature patients so as to minimize the risk of crankshaft, and in cases where one to three fusion levels can be saved by stopping the fusion at the lower thoracic end vertebra\textsuperscript{6, 24,25}. Arthrodesis can be achieved anteriorly, open using single or double rod constructs or endoscopically with a single screw/rod or single screw/dual rod construct\textsuperscript{26, 27} (Figure 8).

Anterior release followed by posterior instrumentation for a Type 1 curve is seldom required presently because the three-column fixation achieved via pedicle screws and the subsequent corrective power achieved often negates the need for a release.

**Type 2: Double Thoracic Curves**
Both of the curves in this group (PT and MT) require fusion, and this is achieved via the posterior approach\textsuperscript{28}. The proximal fusion level is decided based on the magnitude and flexibility of the PT curve, and the preoperative shoulder balance. This dictates whether posterior instrumentation begins at T2 or T3. The lowest instrumented vertebra is identified by the distal region of the MT curve and by the lumbar modifier position\textsuperscript{29} (Figure 9).

**Type 3: Double Major Curves**
Double major curves typically require posterior instrumented fusion to include both the MT (major) and the TL/L (structural minor) curves. For the most part Type 3 curves include the C lumbar modifier due to the apical translation of both structural curves. The sagittal alignment in the thoracolumbar region of these curves is variable and must be considered when planning surgery to optimize sagittal balance postoperatively (Figure 10).

**Type 4: Triple Major Curves**
Type 4 curves are uncommon accounting for only 3% of all operatively managed curves\textsuperscript{17}. The PT, MT and TL/L curves are all structural, and either the MT or TL/L curve can be major. All three curves require arthrodesis, most commonly performed with posterior instrumentation (Figure 11). Occasionally posterior instrumentation and fusion is preceded by an anterior release for a particularly large, stiff, or kyphotic MT or TL/L curve.
Figures 8
(A,B) Type 1B1N curve
Preoperative radiographs demonstrate the major MT curve measures 54º on standing PA radiograph and bends to 19º. The nonstructural PT and TL/L curves bend out to 9º and 20º, respectively. The CSVL through the lumbar apical vertebra demonstrates lumbar spine modifier B. The sagittal thoracic modifier is normal (28º).

(B) Open thoracotomy and instrumentation of the end vertebrae from T7-T11 achieved 28 degrees of correction and maintenance of normal sagittal alignment.

(C) Comparative clinical photos from preop and 1 year postop show good improvement in waist asymmetry, and decrease of the thoracic rib hump.
Type 5: Thoracolumbar/Lumbar Curves
Isolated fusion, either anterior or posterior, of the sole structural TL/L curve is the treatment of choice in Type 5 curves. The authors preferred method is an anterior approach with a dual rod construct and interbody support to maximize construct stability and sagittal alignment (Figure 12).

Type 6: Thoracolumbar/Lumbar-Main Thoracic Curves
Both of the structural curves, the major TL/L and minor MT, require inclusion in the posterior instrumentation and fusion for Type 6 curves (Figure 13).

Figure 9
(A-C) Type 2AN curve
(9A) Preoperative radiographs demonstrate the major MT curve measures 81º on standing PA radiograph and bends to 30º. The structural PT curve bends out to 33º. The nonstructural TL/L curve bends out to 18º. The CSVL through the lumbar apical vertebra demonstrates lumbar spine modifier A. The sagittal thoracic modifier is normal (20º)

(B) Posterior spinal fusion of the PT and MT curves from T3-L1 achieved correction to 22º and 15º, respectively, while fusion of the structural curves alone allowed spontaneous correction of the lumbar curve to 7º

(C) Preoperative and postoperative clinical photographs show elimination of the thoracic rib hump and restoration of shoulder and truncal balance
Figure 10
(A) Type 3C- curve - Preoperative radiographs demonstrate the major MT curve measures 66° on standing PA radiograph and bends to 46°. The structural TL/L curve bends to 30°. The nonstructural PT curve bends to 21°. The CSVL through the lumbar apical vertebra demonstrates lumbar spine modifier C. The sagittal thoracic modifier is minus (+5°)

(B) Posterior spinal fusion of the structural MT and TL/L curves from T4-L4 achieved correction to 17° and 12°, respectively, with spontaneous correction of the nonstructural PT curve to 11°

Figures 11
(A,B) Type 4C+ curve
(A) Preoperative radiographs demonstrate a triple major curve. The major MT curve measures 87° on standing PA radiograph and bends to 56°. The structural PT and TL/L curves bends to 37° and 46°, respectively. The CSVL through the lumbar apical vertebra demonstrates lumbar spine modifier C. The sagittal thoracic modifier is hyperkyphotic (45°)

(B) Posterior spinal fusion from T3-L4 achieved correction of the PT, MT, and TL/L curves to 17°, 27° and 18°, respectively. Sagittal balance was restored to 10° with maintenance of lumbar lordosis
(C) Pre and postoperative clinical photographs show significant improvement in thoracic rib hump, with maintenance of coronal balance.

Figures 12
(A-C) Type 5C+ curve
(A) Preoperative radiographs demonstrate the major TL/L curve measures 43° on standing PA radiograph. The nonstructural PT and MT curves bend to 3° and 11°, respectively. By definition a Type 5 curve carries a lumbar spine modifier C. The sagittal thoracic modifier is hyperkyphotic (45°), but with normal thoracolumbar junctional kyphosis.

(B) Selective anterior spinal fusion of the TL/L curve from T12-L3 with a dual-rod construct and interbody support achieved correction to 13° in the coronal plane and maintenance of sagittal contour.

(C) Preoperative and postoperative clinical photographs show correction of the lumbar rib hump, and waist asymmetry and restoration of truncal balance.
CONCLUSION

Studies have shown the Lenke classification to be reliable and reproducible in its ability to preoperatively categorize and guide treatment of adolescent idiopathic scoliosis, with 90% accuracy in predicting fusion levels when managing a patient though, other factors along with the classification must be considered prior to choosing and instrumenting the fusion levels. These include the clinical appearance of the patient, the level of skeletal maturity and the appropriateness of selective fusion of major curves. The ideal classification for AIS should reflect the current concept of a three-dimensional deformity, and indeed a grade for axial plane deformity was initially sought when creating the current system. However, the difficulties in assessing axial deformity on bi-planar radiographs, and the inherent problems of reproducibility led to this modifier being removed from the scheme. Currently bi-planar...
radiographs remain the gold standard for assessing scoliosis due to the absence of a reliable, available and accepted three-dimensional modality for modeling the spine. If and when such modalities become widely available then the axial modifiers can be added to the current classification system to complement the thoracic sagittal and lumbar spine modifiers.

Since its inception and widespread usage, the Lenke classification has been shown to achieve the six fundamental goals set out at inception. The classification is comprehensive with inclusion of all curve patterns. Emphasis has been rightly placed on sagittal profile and hence the system is truly two-dimensional.

The Lenke Classification of adolescent idiopathic scoliosis

The Lenke Type description lend themselves well to pattern associated treatment methods and aids selection of fusion levels including, when appropriate, selective fusion. It achieves objectivity with well-defined criteria laid out for the differentiation of curve types, and has demonstrated the required reproducibility and reliability with good-to-excellent results.

The high level of inter and intraobserver reliability shown by the classification has enabled the accurate comparison of treatment methods for similar curve patterns this hopefully provides an objective means by which optimal treatment for each patient’s curve type will emerge.

REFERENCES


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COLUNA/COLUMNNA. 2006;5(1):52-63