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Spinal alignment in surgical, multisegmental, transpedicular correction of adolescent idiopathic scoliosis

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Summary

The objective of this study was to discuss the variables influencing alignment mechanisms of the spine, with particular consideration of post-surgical alignment in adolescent idiopathic scoliosis. The analysis is based on information currently available in the literature, and on the authors' own experience, which includes surgical material from over 2200 cases of idiopathic scoliosis.

Over 50% of cases of adolescent idiopathic scoliosis are decompensated before surgical treatment. Spinal alignment is most significantly influenced by the position of the pelvis. Surgical restoration of lumbar lordosis is more important than attempting to restore thoracic kyphosis in the sagittal plane. The sagittal profile has an essential impact on spinal alignment. The same curves in the coronal plane can have various 3-dimensional configurations. Clinical difficulties in the assessment of thoracic kyphosis and lumbar lordosis result from the fact that they undergo constant change with age. Thoracic hypokyphosis diagnosed before surgery is a very frequent symptom of curve progression. The presence of proximal (thoraco-thoracic) and distal (thoraco-lumbar) junctional kyphosis is very important for planning the scope of spondylodesis.

The natural tendency of the spine for alignment (compensation) after surgery nowadays occurs more naturally by applying derotational forces through pedicle screws, compared to the distraction devices (eg, Harrington rod) used in the past.

key words: spinal alignment • idiopathic scoliosis • surgical procedure

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BACKGROUND

Structural deformation (lateral curvature, rotation and torsion of vertebrae), such as idiopathic scoliosis, results in the decompensation of the spine in a significant number of patients (>50%) before surgical treatment. Right-sided decompensation in the coronal plane is the most frequent. Less frequently cases involve anterior decompensation in the sagittal plane, which results from the greater prevalence of right thoracic scoliosis in girls.

The corrective impact of the instrumentation used, in spite of the obtained significant correction of the curve, can lead to further decompensation of the spine, its decompensation towards another side, or restoration of correct balance (body alignment, which is a necessary condition for surgical treatment) [1–7].

A vertical position (both sitting and standing) defines the posture of humans. Alignment is the state of a person standing or sitting with the trunk situated in the centre of gravity, which runs (in a standing position) centrally to a quadrangle of support by the position of the feet (linear alignment) [8]. From a clinical and biomechanical point of view, this state correlates with minimal muscle tone and energetic effort. The vertical line (centre of gravity) determines the central system of human body coordination. It is also the axis of gravity – a crossing point of the coronal and sagittal plane [9–13]. Therefore, body alignment is an active compensatory process in which the head is located symmetrically over the shoulders, the shoulders are symmetrically over the pelvis, and trunk weight is distributed evenly along the vertical axis crossing the center of the sacrum in the coronal and sagittal plane. The effect of gravity and central neuromuscular coordination are generally essential for trunk alignment (balance of forces and moments of force, and the superior role of the central nervous system) [14–16].

In the sagittal plane the position of the trunk undergoes continuous transformations with the process of growth and changes in body position (ie, evolution of spinal curves with age) [10,11]. It is possible to restore trunk alignment in idiopathic scoliosis by forming a compensatory curve above or below the major curve.

Finally, full alignment of the spine will occur when all angular and rotational translocations of vertebrae towards one direction are the same as the angular and rotational translocations of vertebrae towards the opposite direction. The lumbar spine and the position of the pelvis play the most important roles in maintaining or restoring spinal alignment [17–19].

Aim of the study

This paper presents comprehensive knowledge combined with practical experience of the authors in surgical treatment of adolescent idiopathic scoliosis.

This information was gained by the authors by participating in development of the new operative techniques, together with assimilating the knowledge of different scoliosis centers across the globe.

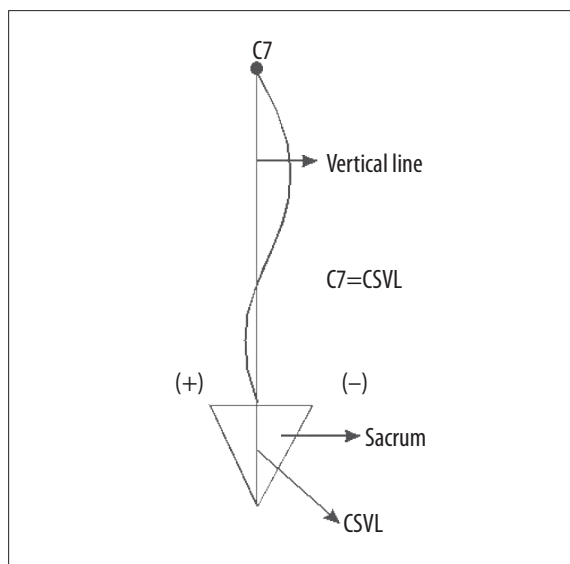


Figure 1. A vertical line beginning at the center C7 body overlaps with the Central Sacral Vertical Line – CSVL crossing the center of the sacrum. C7=CSVL; a full body alignment in the coronal plane. If the vertical line beginning at C7 is located on the right side of the CSVL, it points to right spinal decompensation (+). If the vertical line beginning at C7 is located on the left side of the CSVL, it points to left spinal decompensation (-).

The senior author's experience began in the early 1970s. Since that time, knowledge about scoliosis biology and biomechanics has evolved. It started with Harrington rod constructs, evolved with Cotrel-Dubousset multilevel hook application and finally transpedicular stabilization is nowadays routinely performed. Material include surgical treatment of over 2200 cases of idiopathic scoliosis, among which adolescent idiopathic scoliosis (scoliosis idiopathica adolescentium) occurs in about 85% of all cases treated surgically.

An evolving array of available instruments has allowed a more physiological approach in surgical treatment, with greater ability to correct particular aspects of deformation.

The problem of post-operative decompensation remains significant in some patients, when proper logical approach had been neglected in pre-operative planning.

DISCUSSION

Terms used in the analysis

The impact of multisegmental correction on the alignment of scoliotic spine justifies explaining basic issues related to spinal alignment.

The Central Sacral Vertical Line (CSVL) plays an important role in radiological assessment of lumbar curves in the coronal plane and in determining the distal stable vertebra of a curve. The spine is fully aligned in this plane if a vertical line beginning at the centre of the C7 body and the CSVL overlap (Figure 1).

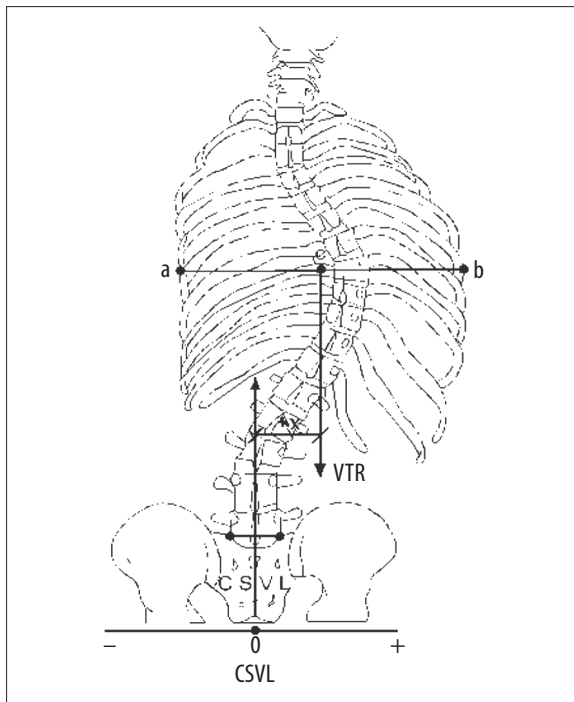


Figure 2. Thoracic trunk shift against the pelvis. Vertical Trunk Reference (VTR) against the Central Sacral Vertical Line – CSVL. c – the centre of the chest determined at the apical vertebra intervertebral disc of the thoracic curve, a,b – a straight horizontal line connecting margins of the chest on the concave (a) and convex side (b) of the curve +X – the value of Vertical Trunk Reference (VTR) against the Central Sacral Vertical Line – CSVL. Negative value (–) – shift of the chest to the left. Positive value (+) – shift of the chest to the right.

If the vertical line is situated on the left side of the CSVL, we deal with spinal decompensation towards the left side (–). If the vertical line beginning at C7 is located on the right side of the CSVL, it points to right spinal decompensation (+). A clinical reflection of spinal decompensation in the coronal plane, in which it is most frequently diagnosed, is mostly a shift of the chest and shoulders against the pelvis. Measurement of thoracic trunk shift assessed on X-ray in antero-posterior projection in patients in a standing position is referred to as vertical trunk reference (VTR) against the Central Sacral Vertical Line (CSVL) (Figure 2) [20].

Global sagittal balance of the spine is assessed on a lateral X-ray performed in a standing position. It is determined by the course of a vertical line beginning at the dens of the axis or the centre of the C7 body. The vertical line that most often crosses the posterior-superior corner of S1 is the sagittal vertebral axis (SVA) (Figure 3).

Positive values point to a shift of the SVA to the front against the promontory (the posterior-superior corner of the S1 vertebral body); whereas negative values point to a shift to the back against it (Figure 4).

From a clinical point of view, the vertical line (centre of gravity) falls slightly to the back of the straight line connecting the centres of the heads of the femoral bones, and

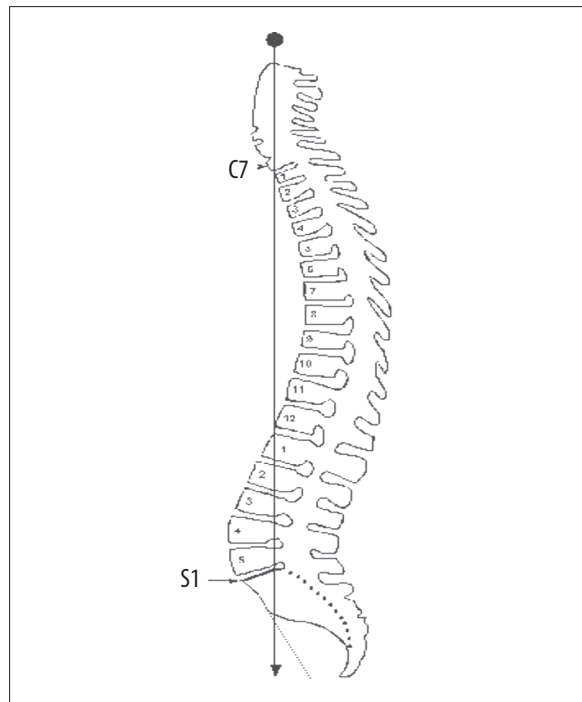


Figure 3. Spinal alignment assessed in the sagittal plane (sagittal balance). The vertical line beginning at the centre of the C7 body most often crosses the postero-superior “corner” of the S1 body.

determines the central system of coordination of the human body. It is the axis of gravity of the crossing coronal and sagittal planes.

Elements of the deformation in scoliotic spine

Difficulties in the assessment of a scoliotic deformation (deformation of vertebrae) result from the fact that it does not have an axis of symmetry. The same curves in the coronal plane may have different 3-dimensional configurations. Stagnara described this situation as an overlapping of a structural deformation and the axis of symmetry of the spine. Simplifying the issue for practical purposes, Stagnara’s *plan d’élection* is a plane of actual, maximal curve formed between the coronal and the sagittal planes [21].

Anatomically, scoliosis is a lateral curve of the spine; according to the clinical definition, it is idiopathic scoliosis. A mathematical definition is based on geometry, and scoliosis is determined as a lateral shift of the line of the vertebral bodies away from their normal, symmetrical position in the line of the middle of the sagittal plane [19].

Progression of rotation of the vertebrae in the transversal plane increases the deformation of scoliosis in the coronal and sagittal planes and has an impact on general decompensation of the spine [16,17].

Lack of linear alignment (imbalance, decompensation, uncompensation) can also occur when the major (original) curve is too long, or when secondary curves are too short and are not “flexible” enough to provide physiological alignment of the position of the spine (stay in shape).

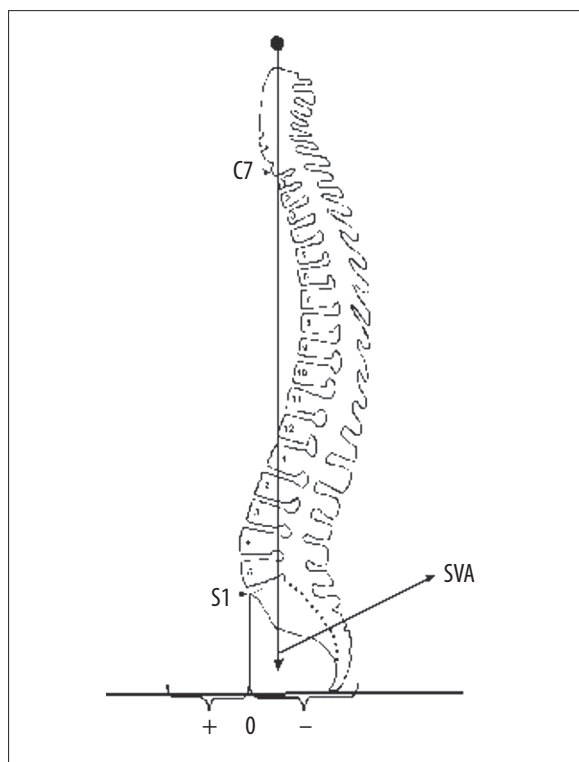


Figure 4. Assessment of spinal decompensation in the sagittal plane. A shift of the vertical line beginning at C7 – Sagittal Vertebral Axis (SVA) to the front against S1 (promontory) is a sign of anterior decompensation (+), while a shift to the back against promontory points is a sign of posterior decompensation of the spine (-).

Decompensation can also occur in spite of sufficient length and flexibility of compensatory curves if they do not show a “normal” compensatory reaction. Patients with single thoracic curves of type III and IV according to King’s classification (with lack of compensatory curves) are usually “decompensated” before surgery. Decompensation also occurs in the case of double curves of a significant angle (80°) of type I and II (according to King) towards major curves (in type I to the left, in type II to the right).

Decompensation of the shoulder girdle (shoulders at different heights) occurs most often in type V (elevation of the left shoulder is caused by upper left thoracic curve); it is less frequent in type III of thoracic curve (elevation of the right shoulder). It can also occur as a result of surgical treatment of scoliosis (overcorrection, or inadequate choice of the proximal and distal extent of spondylodesis). Relations between the position of the pelvis and the position of the spine in the sagittal plane (sagittal alignment) are of essential importance for global sagittal balance [22,23].

A shift of the line parallel to the S1 upper end plate (horizontally situated sacrum) causes anteversion of the pelvis and an increase in lumbar lordosis. In such a situation, maintaining alignment is possible by flexion of legs in the hips (Figure 5).

There is a significant shift of the vertical line (centre of gravity) to the front of the promontory of the S1 (vertical

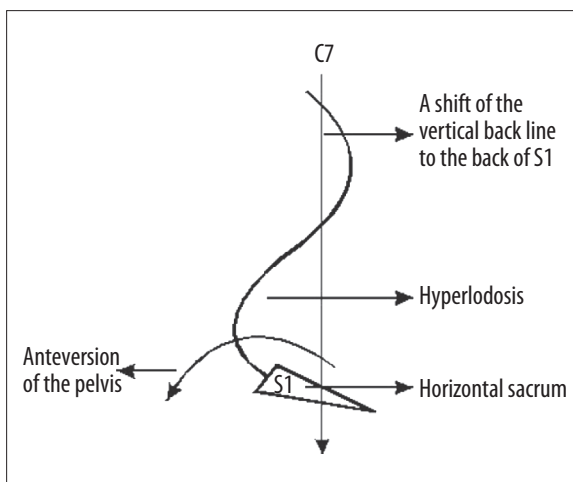


Figure 5. Shift of the vertical line beginning at C7 to the back of S1. Anteversion of the pelvis, increase in lumbar lordosis, horizontal sacrum. In such a situation, maintaining alignment is possible by flexion of legs in the hips (scheme).

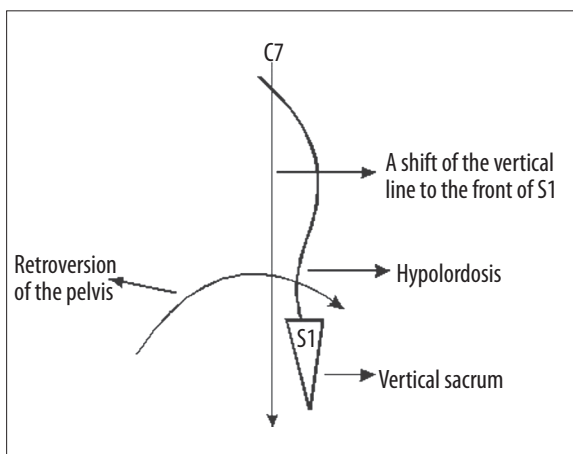


Figure 6. A shift of the vertical line to the front of S1; decrease of lordosis (hypolordosis) or (less frequently) a lumbar kyphosis. Retroversion of the pelvis limits extension in the hips. Anterior decompensation. Flat back syndrome related to the excessive distraction of the lumbar spine (fusion up to L4, L5) in the period when Harrington instrumentation was used. “Flattening” of lumbar lordosis in spite of satisfactory correction of the spine in the coronal plane (application of distraction forces) leads to anterior decompensation of the spine in the sagittal plane (scheme).

sacrum). Retroversion of the pelvis decreases lumbar lordosis (hypolordosis) and limits extension in the hips (Figure 6).

This anterior decompensation in the sagittal plane is the result of, among other factors, surgical distraction of scoliosis within the lumbar spine using Harrington instrumentation when the peripheral hook of the instrumentation most often rested on arches of the L3, L4, and L5 vertebrae (flat back syndrome).

Extension of the fusion

Decrease of lumbar lordosis and leaning of the trunk to the front rarely occurs with current surgical technique using

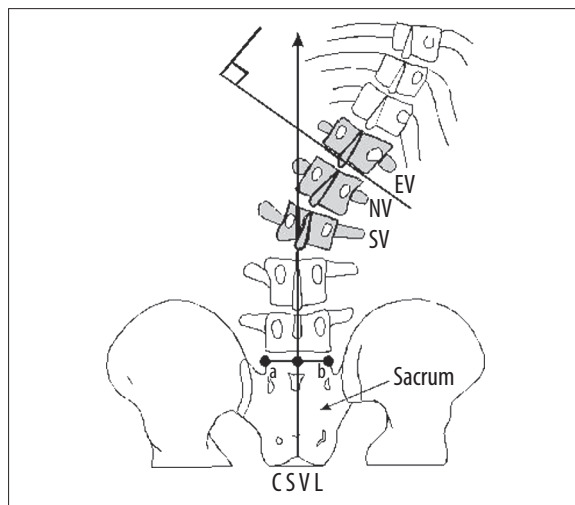


Figure 7. End vertebra (EV), neutral vertebra (NV) and stable vertebra (SV). EV – inferior end vertebra of the curve (end vertebra); NV – neutral vertebra in terms of rotation; SV – stable vertebra crossed by the Central Sacral Vertical Line (CSVL); a, b – horizontal line of the upper end plate of the sacrum S1; CSVL – a vertical line crossing the centre of the sacrum, perpendicular to the upper end plate of the S1.

pedicle screws. To restore spinal alignment, it is much more important to surgically restore lumbar lordosis than to improve thoracic hypokyphosis. It should be taken into account that the angles of kyphosis and lordosis differ individually (kyphosis from 40° to 60°, lordosis from 30° to 80°), and the position of pelvis is of essential importance for maintaining global alignment in this plane. One benefit of clinical and radiological identification of major and minor structural curves that should undergo fusion is enabling spontaneous correction of non-structural curves (classification of types of scoliosis according to King and Moe, and Lenke et al) [24,25]. The classification by King and Moe was published in 1983, when Harrington instrumentation was being used. The authors distinguished 5 types of thoracic curves, although they were assessed only in the coronal plane. This classification was the gold standard in the treatment of scoliosis for over 2 decades and it is still very useful clinically.

In 2001 Lenke et al proposed a more extensive and precise classification of adolescent curves comprising “all” curves (not only thoracic), assessing their correction potential and deformation in both the coronal and sagittal planes. The assessment of curves, as in King’s classification, requires performing X-rays of the whole spine in a standing position on a long film (in both planes), completed with corrective X-rays in lateral tilts (right and left) in supine position. Final classification of idiopathic scoliosis according to Lenke includes 42 patterns of curves. The most significant advantage of this classification is the identification of major and minor structural curves that should undergo fusion in order to enable spontaneous correction of non-structural curves.

Posterior spondylodesis of the fused part of the spine should be as vertical as possible and should be extended in the so-called “stable zone”, resting peripherally on a stable vertebra “crossed” by the central sacral vertical line (CSVL). The stable vertebra should, if possible, be neutral in terms

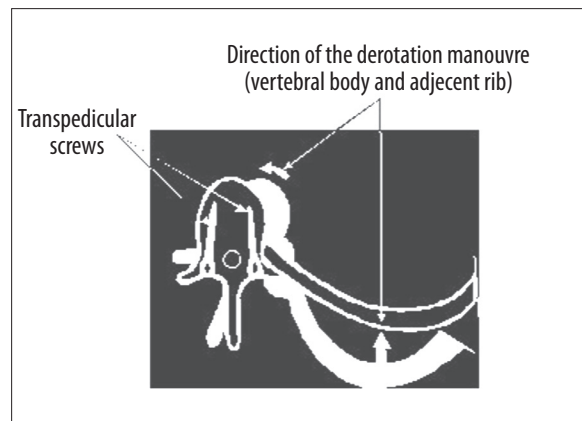


Figure 8. The mechanism of derotation of the apical zone of the curve using pedicle screws. White arrows show derotation of the vertebral segment (white vertebral body and adjacent rib) leading to a reduction of the rib hump.

of rotation and situated horizontally or almost horizontally against the sacrum (Figure 7).

The choice of the upper level of fusion in type V thoracic curve according to King depends on the position of the shoulders.

The multisegmental instrumentation used nowadays, involving fixation with pedicle screws (mono- and polyaxial), provides control of all 3 columns of the spine, increasing its resistance to compressive and distraction forces. The instrumentation based on screws eliminates the involvement of implants in the vertebral canal; therefore it provides more space for formation of a strong posterior spondylodesis. The derotation manoeuvre is an essential element correcting the curve (restoration of spinal curves in the sagittal plane – thoracic kyphosis and lumbar lordosis), and it also reduces the rib hump (relocation of the whole apical zone posteriorly and medially) (Figure 8).

Surgical derotation involves all the screws simultaneously acting on individual segments within the curve (pedicle screws control all 3 spinal columns). This kind of multisegmental fixation rarely leads to post-surgical decompensation of the spine and loss of correction. This instrumentation eliminates distraction and compressive forces, thus enabling passive elongation of the spine and the spinal cord. This significantly reduces the risk of neurological complications (the spinal cord finds its natural length in the vertebral canal). Our experience also points to frugal use of pedicle screws (not necessarily at each level – segment), while bearing in mind general rules determining the extent (scope) of fusion.

Selective fusion

In some idiopathic curves it is possible to shorten the spondylodesis, which is called selective spondylodesis. However, in order to provide post-surgical spinal alignment, eg, in the case of a skeletally “mature” double curve (right thoracic and left lumbar), it is possible to immobilize only the major right thoracic curve, leaving the compensatory left lumbar curve free [24–29].

According to our assessment, selective fusion can be performed in about 30% of patients with double curves. In the case of thoraco-lumbar curves (type II according to King), the major right thoracic curve, left lumbar (correction potential $\geq 50\%$ or $< 40^\circ$ in traction or in lateral tilt) in this case only the thoracic curve requires spondylodesis. In the case of lumbar-thoracic curves (type I according to King), the major left lumbar curve and right thoracic compensatory curve with correction potential of $\geq 50\%$ or $< 40^\circ$ in traction and in lateral tilt, only the lumbar curve requires spondylodesis.

In the case of double thoracic curves (type V according to King), when the major curve is a right thoracic curve and the compensatory curve is an upper left thoracic curve (undergoing correction of 50% or $< 40^\circ$ in traction or in lateral tilt), only the major right thoracic curve requires fusion. Finally, the decision to perform selective fusion in type V depends on the position of the shoulders. If the left shoulder is situated higher (in this structural left thoracic curve), both thoracic curves should be fused in order to restore the horizontal position of the shoulder girdle ("shoulder girdle alignment"). If the right shoulder is situated higher, spondylodesis should be performed only in the lower right thoracic curve in order to provide alignment of the shoulder girdle [4,20,24,25,30]. Therefore, the following factors should be taken into account while planning selective spondylodesis: bone maturity, correction potential, and rotational changes of compensatory curves.

Another important factor to be considered while making a decision on performing selective spondylodesis is the presence of proximal (in the case of double thoracic curves) and distal (in thoraco-lumbar curves) junctional kyphosis. If it is present, both curves (the major and the compensatory) require fusion. Performing selective fusion within the major curves only (in skeletally immature scoliosis with Risser test = 0–3) may pose a risk of post-surgical decompensation, which may also occur when dealing with fixed structural changes of secondary curves (inadequate assessment of their pre-surgical correction potential) or excessive surgical correction of the major curve (taking into account its pre-surgical correction potential) that exceeds the accommodation potential of the compensatory secondary curve.

The essence of skilful use of multisegmental instrumentation and pedicle screws lies not in aiming to achieve maximal correction of the curve, but in using possibilities offered by segmental derotation manoeuvres that lead to satisfactory correction and restoration of body alignment until a strong spondylodesis is formed within 18 to 22 months [4,15,31–34].

It should be emphasized that an adequate choice of the lower level of fusion is the most important factor influencing the result of surgical treatment. Currently, surgical treatment of thoracic and thoraco-lumbar adolescent idiopathic scoliosis $< 60^\circ$ (with the use of multisegmental instrumentation and pedicle screws) is mostly based on a posterior approach, which involves less risk.

Combined anterior-posterior fusion

Combined anterior and posterior fusion is justified in the case of large, "rigid" curves exceeding 80° , as well as in

"immature" or decompensated curves. In all such cases a crankshaft phenomenon is likely to develop [35–38] in which we may observe further growth of the frontal spinal column after posterior fusion. The curvature is progressive in patients with immature bones (growth of the frontal column of the spine) around the strong posterior fusion. The fused spine becomes "pulled into" the progressing scoliotic rotational deformity. The post-surgical crankshaft phenomenon occurs mostly in children with open Y-shaped cartilage of the acetabulum and Risser test scores of 0 or 1 and Tanner scale < 2 . An important factor in preventing the crankshaft phenomenon is an anterior "release" (multilevel discectomy) followed by correction of the curve and its fusion from a posterior approach using multisegmental instrumentation and pedicle screws.

CONCLUSIONS

We have discussed essential issues concerning spinal alignment, with particular consideration of post-surgical alignment in adolescent idiopathic scoliosis.

1. Post-surgical spinal alignment is essential to surgical treatment of idiopathic scoliosis, which can be achieved not only by using up-to-date published information, but also needs great clinical experience, passed on between generations of spine surgeons.
2. The position of the pelvis against the lumbar spine is of great importance for global spinopelvic balance. The essence of surgical treatment is not maximal correction of the spine in the coronal plane, but rather safe derotation leading to restoration of spinal alignment after surgery.
3. Consideration of selective spondylodesis must take into account bone maturity, size, rotation, and stiffness of compensatory curves. It is also essential to confirm the presence of junction kyphosis in proximal (in double thoracic scoliosis) and in distal regions of deformation (in thoracolumbar scoliosis). In those cases, primary and compensatory curves both require fusion.
4. The surgical technique involving multisegmental instrumentation and pedicle screws acting on all 3 columns of the spine is mostly based on applying derotational forces, which enables passive elongation of the spine and the spinal cord (the spine spontaneously finds the best position). The derotational manoeuvres eliminate the use of excessive segmental distraction and compressive forces. In our opinion, pedicle screw fixation is not always necessary in each segment.

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