SELECTED LECTURES

ON SPINE SURGERY

ACHIEVING HARMONY IN 3D CORRECTION OF SPINAL DEFORMITY

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Achieving harmonious correction of scoliotic deformity requires a clear understanding of this condition with respect to the spinal column. Achieving harmony is not a pursuit of mandatory reduction of the Cobb angle. The main goal of the treatment is to achieve alignment, balance and stability of the spine.

This goal should be taken into account both in the planning of surgical intervention, and at all its stages. It is very important to correctly determine the extent of the spinal fusion zone, to select an adequate type of endocorrector fixation and the nature of corrective maneuvers. Intraoperative achieving of harmony is aimed at correct distribution of body masses and their position relative to the load axis.

The harmony of the human spine is hardly described mathematically, but it is achievable when using some benchmarks: alignment, body mass distribution, and 3D static and dynamic balances.

Key Words: scoliotic deformity, 3D correction, balance, harmony.

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Today, each of the members of the spine surgery community is thinking in three-dimensions. Let us recall that until the late 1970's, most patients underwent only frontal spondylography supplemented in rare cases by lateral one. In the past 20 years, spine surgeons have focused efforts on the sagittal plane. The lateral spondylogram provides a large number of parameters; however, an anterior-posterior projection is often ignored, which automatically distorts the measured parameter. This, in turn, introduces errors in the formulas used in planning of surgery. Many surgeons around the world completely ignore deformity in the horizontal plane because they usually associate these changes with CT scans at the level of any single vertebra. 3D changes in the horizontal plane can be evaluated only by considering the deformity as a whole, as it is performed when examining a 3D image of the spine in the craniocaudal direction. This examination requires modern techniques with three-dimensional reconstruction of the spinal column. This can be done by CT, but the necessary dose of radiation is unacceptable for children and adolescents; therefore, low-dose or non-radiation techniques are required. Furthermore, a simplified technique of 3D image analysis using the EOS imaging system, which was proposed by Tamas Illes, helps to evaluate the relationships of vertebral elements, alignment, and balance of the spine as a whole. The last thing that prompted me to write this article was the general trend in correction of spine deformities with focus on a Cobb angle reduction on the frontal spondylogram and maximum derotation of the vertebrae. The current trend of using pedicle screws in any situation and at any level often leads to significant changes in the frontal and sagittal planes. Straightening of the spine in these two planes leads to inharmonious correction and, often, to elongation of the instrumentation area.

The purpose of this lecture is to clarify the philosophy, principles, and techniques for achieving harmonious 3D correction.

What is harmony of the human spine and body? Three key words define the purpose of treating spinal deformities: alignment and balance ensure stability in movement, which is reflected by the cone of economy concept during achieving the normal posture and function in the chain of trunk balance. Here, it is necessary to add the term "harmony" in the sense as Paul Belligue (1892–1955), professor of anatomy at the Paris School of Fine Arts, defined it: "Harmony is the Sister of Economy" (Fig. 1). In music, harmony is consonance of different tones; this is the rule of physics. The opposite is dissonance of sounds. In visual arts, harmony is consistency in the arrangement of successive colors and shades. The opposite is a color conflict. For the spine and trunk (shape and movement), harmony is the correct distribution of body part masses (head, chest, abdominal cavity, pelvis, and hanging upper limbs). In reality, it is difficult to classify this concept because of traditional, cultural, and educational subjectivity in the perception. That is why so little has been done to use this concept in pre- and postoperative assessment of the patient's spine condition.

We should remember that the human is harmonious both in statics and in dynamics. This means a correct and good-looking arrangement of different body parts in accordance with the size, shape, weight, alignment, and performed movements. Therefore, harmony exists for high and low, smooth and coarse forms, for

thick and skinny ones, and suggests correct and balanced movements. I believe that harmony should be the goal of treating spinal deformities in the coming decades. In the first years of using CDI, we quickly realized that pursuing the minimum angle of Cobb was not the main thing. Even in the case of a large residual angle, the achieved body mass distribution is more important. This is the main point of the philosophy and technique of CD, but we did not pay attention to this circumstance when taught colleagues (Fig. 2, 3).

A good example for explaining harmony is the spontaneous evolution of a proximal humerus fracture in a growing child. Even in the case of a significant displacement of fragments reflected in an X-ray picture, remodeling occurs spontaneously, and the harmonious shape of the bone is restored at the end of the growth period. In the case of the spine, transpedicular osteotomy performed at a single level (40°) to restore lumbar lordosis may lead to disharmony. A similar outcome is avoided if less invasive sequential multilevel osteotomy (10° per level) is used, which enables gradual correction with a harmonious alignment of the vertebrae. With respect to idiopathic scoliosis, there are many examples of the use of modern instrumentation, especially a variety of pedicle screws at any level. In these cases, excellent correction on a frontal spondylogram is often accompanied by flattening of the sagittal contour and, sometimes, persistent scapular elevation due to frontal hypercorrection. In contrast, the results of applying the first CDI variants in the case of significant but incomplete correction of the Cobb angle demonstrate excellent and very sustained over 30-year follow-up) 3D correction through redistribution of body part weights. It should be remembered that in the presence of two primary curves, the balance can be achieved if both curves match all the criteria of harmony and balance, even despite a significant Cobb angle. Sometimes with age, these deformities are associated with the development of changes (with or without pain syndrome), thoracolumbar kyphosis, and disturbance of harmony. This suggests that harmony is a status that should be considered upon assessment and treatment of spinal deformities. We will try to determine the ways for solving these problems.

Fig. 1
Harmony is the Sister of Economy

Preoperative preparation of vertebral structures. Preparation is necessary, e.g., in the case of rigid deformity, lung function deficit, secondary progressive neurological symptoms, etc. In these situations, preoperative traction using a halo apparatus or a distraction cast may be very useful for a number of reasons, including normalization of the spine alignment, increased spine mobility, and marked improvement in the lung function (traction is used until the lung function reaches the plateau stage; sometimes, it takes several weeks). These also include changes in the neurological status, which, on the one hand, may indicate an increased risk of intraoperative manipulations and, on the other hand, demonstrate regression of symptoms and prevent the need for intracanal decompression of the spinal cord. The traction period should not be prolonged to avoid the development of osteoporosis. In addition, in the preoperative period, it may be necessary to teach the child how to use a breathing apparatus that may be required immediately after surgery. Each case is unique, but this stage should always be kept in mind.

Planning of surgery. An X-ray image of the spine is only a projection shadow of the anatomical structure that in reality exists in three-dimensional space. This is very clearly seen in 3D reconstruction of thoracic curve progression when viewed in the craniocaudal direction. It becomes clear how the loading line passes – through the sequence of vertebrae, positions of the apices and transitional segments of the scoliotic curve, and torsional changes, regardless of the etiology of scoliosis (idiopathic, paralytic, dystrophic, or degenerative). Of course, it is necessary to consider the patient's whole body position in terms of the chain of balance concept that includes positions of the cephalic and pelvic vertebrae relative to the loading axis. Finally, it is necessary to evaluate the active muscle potential that provides compensation at strategic levels of the chain of balance.

1. The first stage in planning of correction, after deciding to perform surgery, is to compile a general picture of the body, including the head and feet, in statics and dynamics, to represent the overall appearance and function (Fig. 4). This picture should correlate with X-ray images of the whole spine (or even the whole body), which represent all segments, curves, and their apices and transitional regions (vertebrae or intervertebral discs).

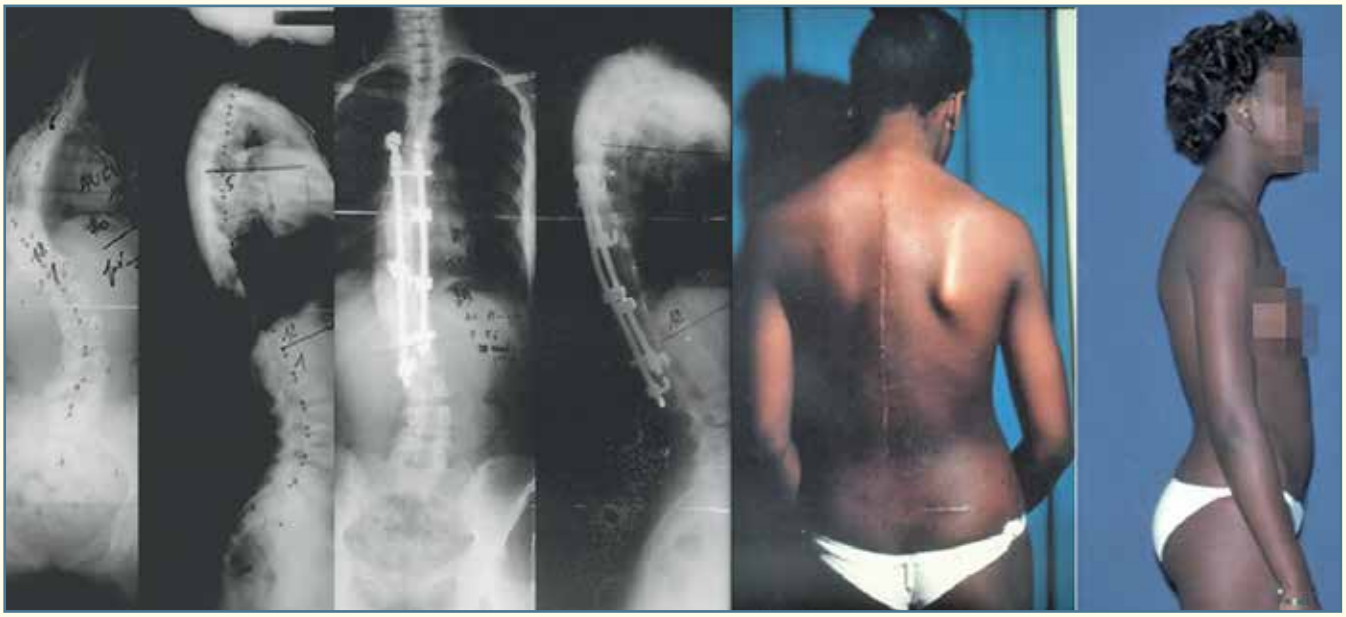

Fig. 2
Early experience with CDI: the spine is not straight, but harmony is achieved

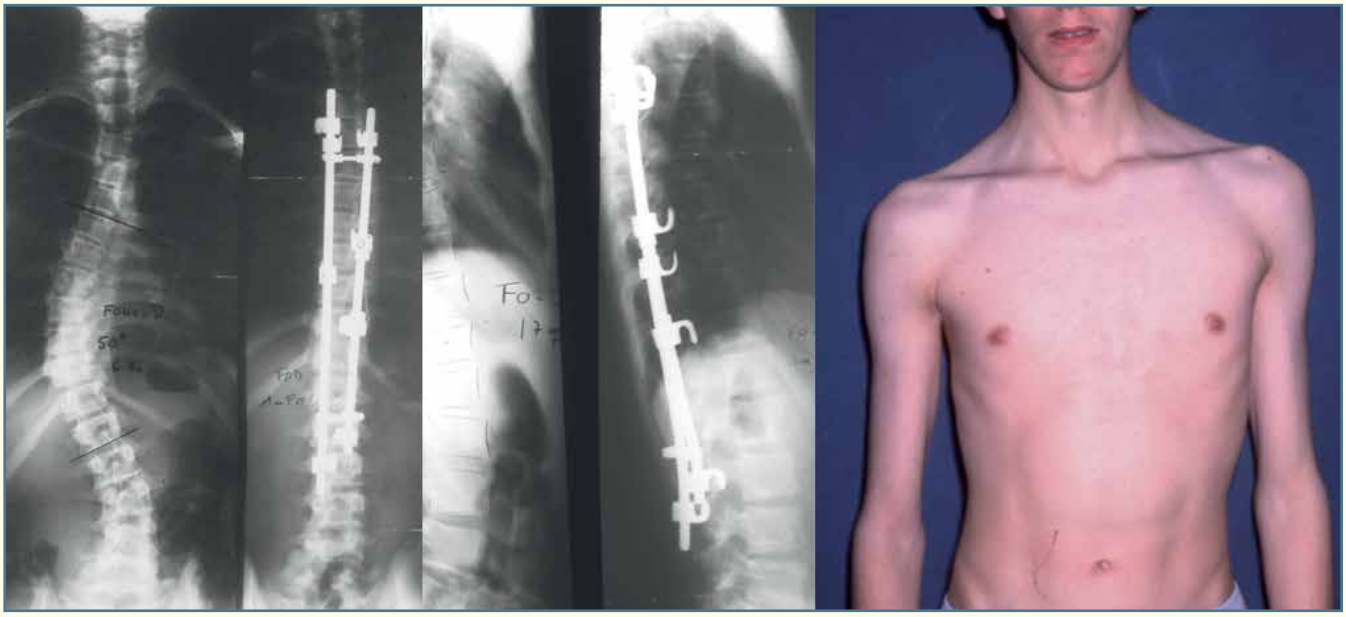

Fig. 3
Early experience with CDI: the spine is straight, but complete harmony is not achieved

2. Functional spondylograms in lateral (passive) or traction bendings help to evaluate structural (axial rotation and torsion are generally remained in the case of passive correction of the curve) and non-structural (compensatory) deformities where torsion completely disappears (Fig. 5). It should be remembered that regardless of the reference plane position, mobility is controlled by structural changes at the curve apex and in the transitional regions (Fig. 6). This approach is mandatory for determining the correction strategy, precise positioning of implants, and order of manipulations, namely: the beginning on the concave or convex side, formation of kyphosis and lordosis, and orientation of the pelvic curvature in neuromuscular scoliosis.

3. Length of the instrumentation and fusion area. We should always remember that the shorter the spinal fusion area, the

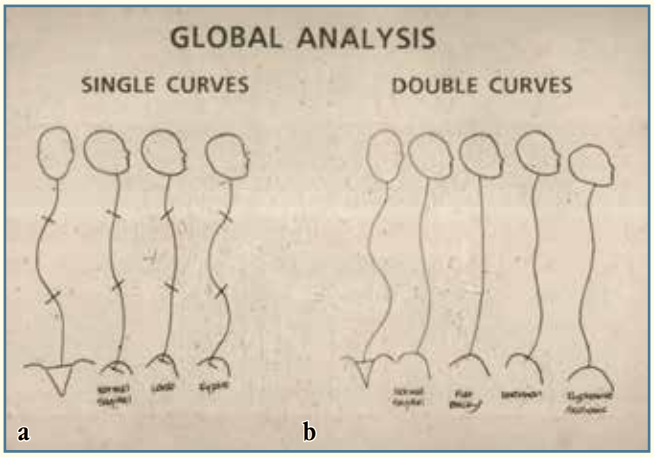

Fig. 4
Global analysis: **a** – single curve; **b** – double curve

longer the preserved mobility area. But in this case, there should not be free unstable segments and segments that can eventually lose stability and correct orientation in space. That is why only structural deformities should be included in the block area. Conversely, compensatory curves should be left free because, after proper correction of the structural curve, the compensatory curve disappears or decreases to a degree sufficient to preserve the balance in the presence of free mobile segments.

This applies equally to the upper thoracic and lumbar counter curves. Planning should be thorough in terms of identification of very short transitional regions that are sometimes represented by just one intervertebral disc between L3 and L4 or L4 and L5, and sometimes between L1 and L2, and left free, which may lead to decompensation or progression of the curve (adding-on phenomenon). The best way to prevent the development of this complication is to evaluate the axial rotation of these vertebrae in plain and functional spondylograms. In the case of full correction, there is no need to include these vertebrae in the block, but if rotation remains, their inclusion is recommended. It is useful to examine, e.g., in lumbar or thoracolumbar radiographs with active lateral bendings, the shape of the disc that is supposed to remain free immediately below the fused area. If it opens symmetrically to the right and to the left, there is no problem, and this level can be left free (Fig. 7). On the other hand, when an unstable vertebra is identified (superjacent and subjacent discs are extended bilaterally), the disc should be included in the block to prevent the shearing effect (Fig. 8). The same situation occurs in the case of double thoracic deformities – a T1 slope of up to 15° is compatible with normal life; if this indicator in a lateral bending is greater, spinal fusion should be extended to the upper end vertebra. In the presence of two primary curves, thoracic and lumbar, depending on their mobility, the thoracic or lumbar curve only can be fused, and the approach can be only anterior, or only posterior, or combined, but the previously described rules are also valid in this situation.

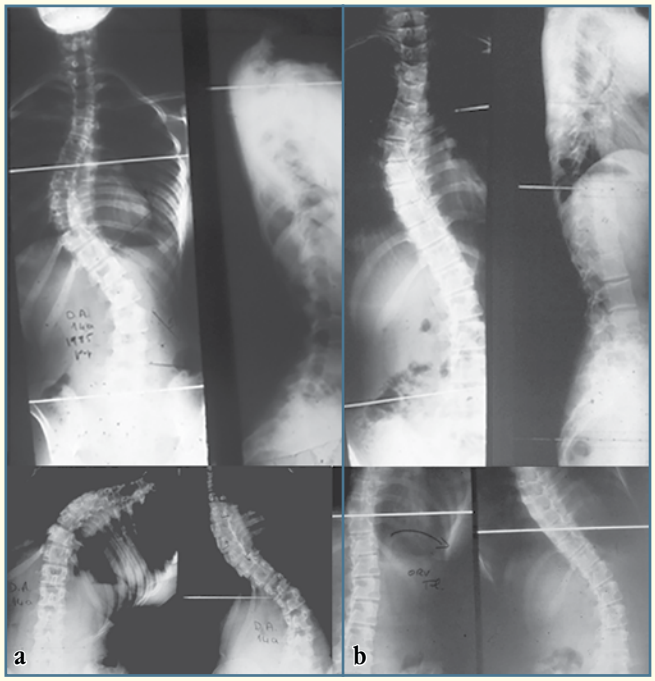

Fig. 5
Compensatory **(a)** and structural **(b)** curves: functional images are mandatory because they demonstrate capabilities of derotation

4. Selection of the implant and its position. Despite the fact that many surgeons now fix each vertebra with two pedicle screws, we believe that the advantages of this fixation (provided that there is no osteoporosis) are counterbalanced by inconveniences due to a relative proximity of implants. At these conditions, stiffness of the spine together with stiffness of rods prevents self-alignment of the corrected spine. Therefore, we prefer to place implants (hooks or screws – along the direction of the corrective force) on the strategic vertebrae: upper and lower end, apical, and intermediate (on the concave side) vertebrae. Of course, the vertebrae in transitional regions should be instrumented on both sides. In special situations, specific solutions are required. In the upper thoracic spine, the fusion area should be ended by two supralaminar hooks that are better than screws. On the other hand, if pelvic fixation is required, iliosacral screws are preferable because this is the most reliable and safe method of pelvic fixation. Planning is completed by plotting the location of implants and all planned manipulations (rotation, distraction, compression) on a spondylogram or a sheet of paper (Fig. 9).

5. The choice of a rod and its proper bending, as well as the metal from which the rod is made, is very important. This can be stainless steel, chromium cobalt, or titanium. Each of them has its own elasticity, rigidity, etc. Their compatibility with a MRI study is no less important because artifacts disturb interpretation of images. The rod should be bent for two purposes. The first is the possibility of restoring the sagittal spinal contour to normal parameters. Therefore, in scoliosis, bending should be

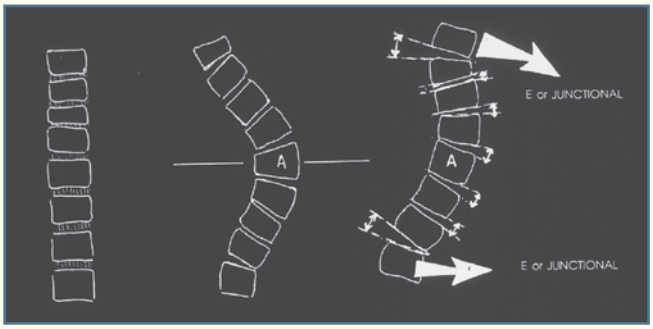

Fig. 6
Surgical correction of the main curve: mobility is determined by structural changes in the apical and transitional regions

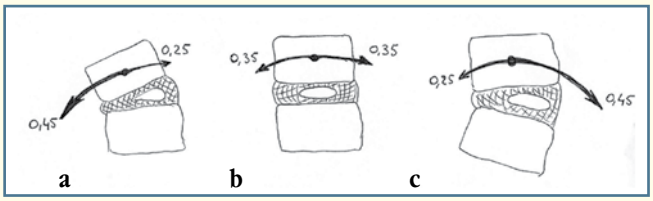

Fig. 7
Preservation of a single level is not the best concept if this level is not sufficiently balanced in space: **a** – balanced; **b** – ideal; **c** – unstable

different in the thoracic and lumbar spine. The second purpose is the possibility of performing an axial rotational maneuver to restore kyphosis and lordosis and horizontal translation of displaced vertebrae. Bending should always be progressive and smooth, never sharp or angular, otherwise there will be points of metal weakness, and sliding of the rod in implant heads will be complicated during compression, distraction, or rotation. It should never be forgotten about the possibility of bending the rod *in situ* when it is useful or necessary.

6. Corrective maneuvers. I attach great importance to positioning of the patient on the operating table and the approach type – ventral or dorsal. For example, in the case of a dorsal approach during surgery for scoliosis, when the spinal fusion area reaches the lower lumbar spine, lifting of the pelvis to achieve the required lordosis value is very important. In addition, I prefer to operate under axial traction conditions (regardless of the approach type) using either a temporary halo apparatus or an adapted soft head holder, when traction is applied to the lower limbs (or one limb) by means of adhesive tapes or special shoes. Traction applied to one lower limb is especially useful in the oblique pelvis because asymmetric traction provides a significant part of correction, reducing the forces generated by tools. After performing a surgical approach, implant placement levels are determined using anatomical landmarks or fluoroscopy. Hooks and/or screws are then implanted in accordance with

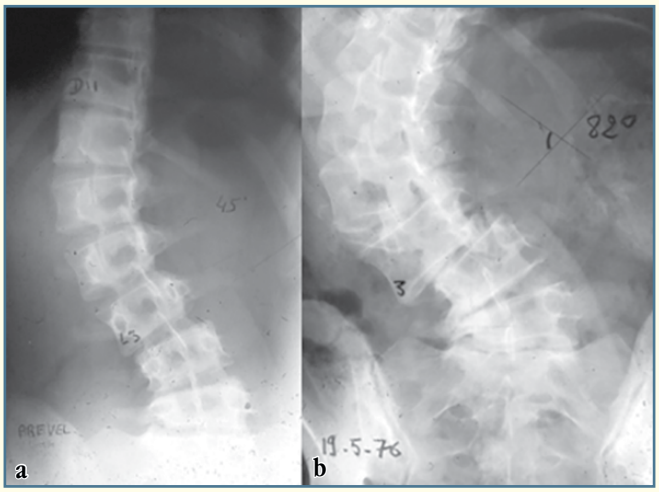

Fig. 8
Shearing effect: **a** – age of 16 years; **b** – age of 39 years

preoperative planning. After release or excision of the intervertebral joints or Ponte osteotomy and resection of soft tissues that may interfere with the bone block formation, a corrective maneuver is started: on the concave side of the thoracic curve in thoracic scoliosis or on the convex side in lumbar scoliosis. The order of rod insertion, compression, distraction, and rotation (in the whole or in segments at each level) is performed in accordance with the preoperative planning.

Intraoperative achievement of harmony. From my point of view, intraoperative traction is a very good procedure for achieving harmony at the end of surgery. This correlates with experimental studies by Lewis Sayre (1877) where traction applied to a spine model reduced the spine curvature degree.

Rotation of the rod in accordance with the gentlemen's agreement between stiffness of the rod and stiffness of the vertebral structures provides correction due to mobility existing between the strategic vertebrae identified before surgery. These movements occur in three planes and explain why, after rotation of the rod, if the strategic vertebrae are chosen correctly, there is smaller flattening in the sagittal plane compared to total pedicle screw instrumentation (Fig. 10). For the same reason, the outcome, in terms of harmony, of translation by means of less rigid sublaminar clamps is better than that of pedicle screw implantation at all levels.

However, the most important thing in harmonious correction is not to achieve the minimum Cobb angle on a frontal spondylogram, but to maximally normalize the sagittal contour of the thoracic and lumbar spine, even at the expense of slightly smaller correction of the frontal curvature. This also applies to axial derotation when the maximum correction of a rotational deformity component means implantation of pedicle screws at all levels and leads to the above problems, but does not provide the desired harmony. It is time to think not only about angles but also about body part masses and their redistribution along the loading axis, while the patient is standing and moving, in

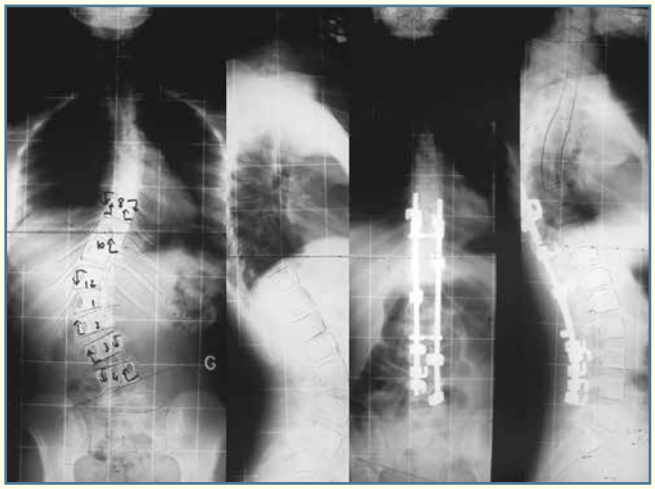

Fig. 9
Preoperative planning

accordance with the patient's age, motor activity, and compensatory capabilities. It does not make sense to correct deformity in elderly patients, creating a very extened spinal fusion area from the pelvis to the T2 vertebra with screws at all levels, as it is done in adolescent or middle-aged patients. For me, there is nothing surprising in frequent development of PJK in these patients. Be very careful when deciding to extend the spinal fusion area to the sacrum because preserving pelvic mobility is very important for achieving compensation. In my opinion, it is better to perform as short as possible spinal fusion, sparing the dorsal musculature, and to consider in certain cases short anterior fusion with less obvious correction, but with a better functional outcome.

Postoperative examination. In the recent past, postoperative examination was limited to measuring the Cobb angle and calculating the percentage of achieved correction. The same applied to comparison of different correction techniques in terms of their efficacy, which prompted surgeons to attempt to achieve the maximum possible angular correction and reduce the final Cobb angle to zero. An analysis of similar cases demonstrated how far we were from achieving harmony of the trunk in shoulder imbalance, asymmetry of the waist triangles (non-ideal thoracolumbar transition), and flattening, if not complete smoothing, of the thoracic kyphosis. On the other hand, there is often a decrease in the lumbar lordosis with subsequent changes in the thoracic spine, while in other cases, especially if anterior instrumentation is used, there may be sudden development of wedging of the subjacent transitional disc and doubts about its further fate (accelerated degeneration). Therefore, from our point of view, postoperative evaluation of the result should be as follows.

1. Clinical evaluation: the presence or absence of three-dimensional harmony; it is useful to photograph the patient from three points. Optical topography is a reliable non-invasive tool for evaluating the body shape in dynamics in combination with measurement of a rib hump and with a scoliometer for assessing scoliosis in the horizontal plane.

2. Another clinical evaluation: the function of walking, running, and climbing the stairs; the ability to squat and stand up from this position. How harmoniously are all these tasks executed? If a study is conducted at regular intervals, a simple chronometer will help to evaluate the performance of this test and changes in the results during follow-up (I use the squatting and standing up test to evaluate the aging process in the general population).

3. Radiography of the entire spine and comparison of the measurement results with preoperative ones. It is very important to evaluate mobility of the disc located caudal to the lower instrumented vertebra for predicting degenerative changes (Fig. 11). A free spine region is evaluated in two planes: lateral bendings and flexion-extension. If the lower disc is more or less symmetrical in different positions, this is a predictably good sign. However, I would not recommend postoperative examination through its entire length using only a radiation technique (even low-dose), especially in children and adolescents because of the risk of inducing cancer. I recommend a non-invasive technique and X-ray if the non-invasive technique reveals significant changes in the patient's condition. This approach is changed only in the case of persistent pain and suspicion of an inflammatory process.

Conclusion

Even if it is difficult to represent mathematically the harmony of the human spine because the criteria are dependent on the subjectivity of estimates that, in turn, vary depending on the age, education, historical background, and, sometimes, changes in the basic definitions of society, we should suggest some landmarks:

– three-dimensional smooth alignment according to the weight, height, and age;

– acceptable distribution of the body weight, from the feet to the head;

– three-dimensional static balance within a small cone with an individual shape of the latter in each patient;

– ability to perform three-dimensional movements within normal basic functional performance.

All these facts explain why we are far from considering the Cobb angle as a gold standard. For many years, the Cobb angle has been very useful, but its application without a deep understanding of its capabilities may lead to errors.

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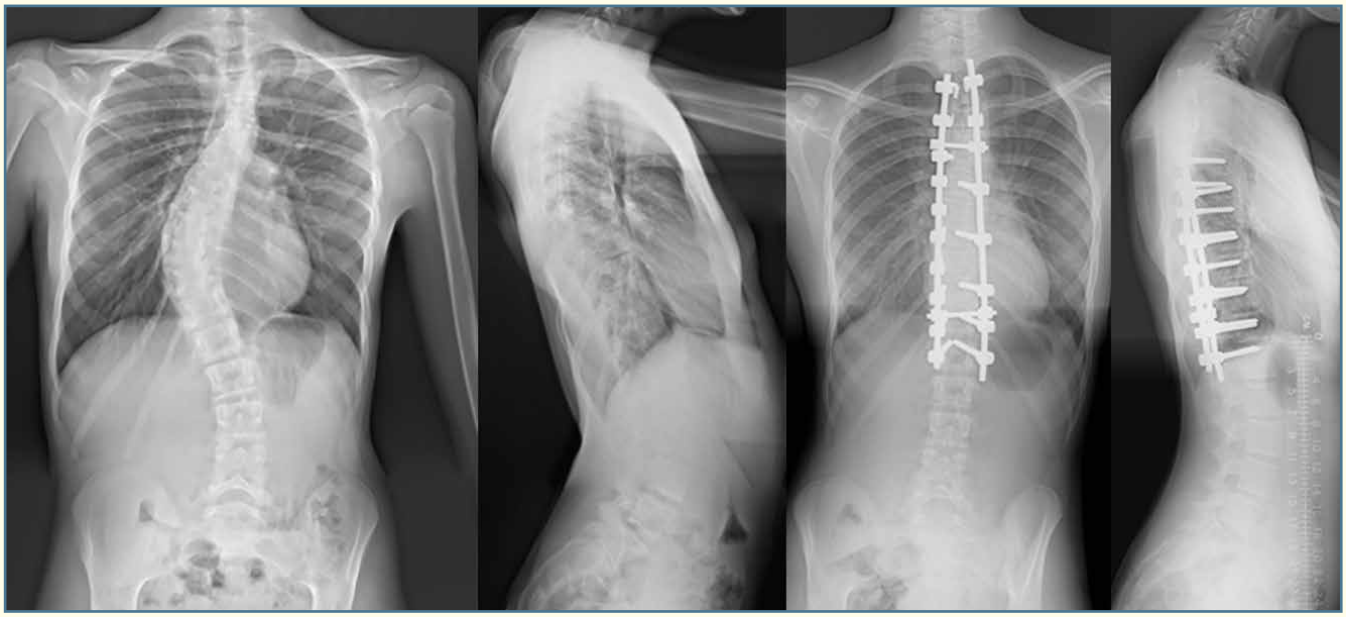

Fig. 10
Pedicle screws at all levels: imbalance, shoulder asymmetry, flattening of thoracic kyphosis. There is no harmony!

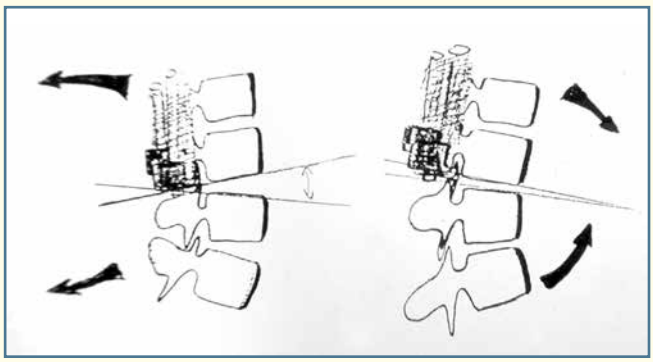

Fig. 11
After surgery, unblocked segments become the most important part of the spine. They should be balanced in 3D, both in statics and in dynamics

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