THREE-DIMENSIONALITY IN VERTEBRAL PATHOLOGY: THE HORIZONTAL PLANE IS HIDDEN IN EVERY SCOLIOTIC DEFORMITY

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The main idea of the paper is that any scoliotic deformity of the spine is a deformity primarily occurring in the sagittal plane. This statement is confirmed by anatomical and clinical data, results of the use of imaging techniques, and biomechanical data. The proposed concept significantly affects the solution of strategic and technical problems in the course of both conservative and surgical treatment of patients with scoliosis. It should be realized that scoliotic deformity is a compensatory response within the balance chain to a rotational phenomenon occurring in the frontal plane. The goal of the doctor is to achieve the balance of the patient's body through understanding its three-dimensionality and realizing the importance of taking into account the horizontal plane.

Key Words: scoliosis, horizontal plane, torsion, balance.

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Despite a huge number of historical works and descriptions, as well as the increasingly frequent use of the term “3D concept”, in most publications somehow related to scoliotic deformity, their authors, as well as practicing surgeons, have focused on the frontal and, in recent years, sagittal planes.

They have used the 3D concept in planning surgery, describing reduction manipulations, and assessing intervention outcomes, but the Cobb angle has remained the “gold standard” for them, and it seems that they partially or completely have ignored the fact that the horizontal plane is, by definition, the reference for any deformity of the human spine. However, we should understand that the horizontal plane in spinal deformity is not only one of the computed tomography aspects; it is the plane on to which the stack of vertebrae is projected on the ground (no matter, in the top or bottom view), with each vertebra occupying its own position in accordance with the alignment of this complex deformity (Fig. 1).

The purpose of this article is to explain:

1) why any (regardless of etiology) scoliotic deformity is a deformity in the horizontal plane;

2) what are the optimal clinical and imaging technologies that help solve the discussed problem, in particular in quantitative terms;

3) how does the proposed concept affect the choice of strategic and technical tasks in conservative and surgical treatment of scoliosis patients;

4) why does this concept provide a new approach to assessing the patient’s condition before and after treatment, including quantitative assessment, both in terms of 3D visualization and performance.

Why any (regardless of etiology) scoliotic deformity is a deformity in the horizontal plane? There are many reasons for considering this concept.

1. Anatomical considerations. If we have the skeleton of a scoliotic spine of any etiology (in an upright position specific to the normal human condition), it is easy to determine the horizontal torsion of not only a set of individual vertebrae involved in the common chain in accordance with the axis of gravity. We note the transverse twisting at the level of each vertebra and intervertebral disc. This applies to the half-arches, transverse processes, and pedicles (thinner on the concave side and wider on the convex side of deformity), as well as vertebral bodies if it is the adult spine specimen. This fact was marked by researchers in past centuries, and even before the discovery of Roentgen rays, many authors (Shaw, 1824; Adams, 1865/1882; Bouvier, 1879) described or depicted these findings in their works [1–3]. In particular, Rene Perdriolle [4] explored a scoliotic spine specimen and convincingly showed that the length of its anterior column was significantly longer than that of the posterior column, which was also demonstrated in a book by Shaw [1]. The projection associated with the rotation of a vertebra in the horizontal plane shows that a “shadow” of kyphosis is actually the lordotic position of one vertebra relative to the other.

2. Clinical considerations. The clinical diagnosis of structural scoliosis is based on the so-called Adams test that shows a rib hump (due to axial rotation of the vertebrae with rib deformity) in the thoracic spine or a prominence of the paraspinal muscles on the convex side of deformity caused by the underlying transverse processes in the lumbar spine. The scoliometer developed for this test [5] is used both in diagnosis and in assessment of the treatment outcomes.

Another clinical test is used in the early or late diagnosis of scoliosis (especially in lumbar deformity). This is the so-called window symptom, which is assessed when the patient is examined from the front, more often from the back. With the patient being in a standing position (in the absence of leg

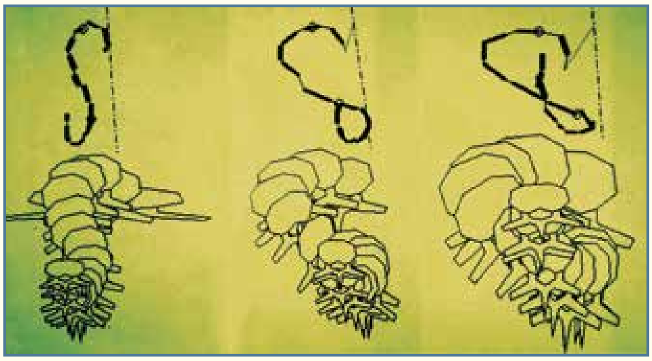

Fig. 1
When viewed from above, the changes in the horizontal plane are obvious

length inequality), the waistline and, accordingly, the size of the triangle between the inner surface of the freely hanging arm and the lateral trunk on side are evaluated. In the case of asymmetry of the right and left sides, there may be lumbar scoliotic deformity with translation of the lumbar spine in the horizontal plane laterally, anteriorly, or posteriorly.

Talented researchers, e.g., the Ducroquet brothers in 1965 [6], emphasized importance of the horizontal plane after studies of patient walking within a room whose walls were completely covered with mirrors. It is the horizontal plane in which the spine alignment and balance of the shoulder girdle and pelvis are achieved relative to the polygon of support during walking, called the "pelvic step".

If we examine a patient with scoliosis of any etiology, a child or an adult, young or old, in a standing or sitting position, and look at him from top to down, we very quickly find that spinal deformity always has a horizontal component, pronounced or mild, but always present. This was described in the book by Adams [2] and confirmed by modern studies.

3. Imaging findings are numerous, if not endless. First, we should remember that conventional radiography is a one-plane projection (shadow) of a three-dimensional object. This is especially typical of scoliosis. Historically, only anteroposterior projection views were usually used at the beginning of the X-ray era. The lateral projection was rarely used if there were special indications for it, e.g., Scheuermann's kyphosis. Many authors have emphasized importance of the horizontal plane in examination of the scoliotic spine [7, 8]. In 1968, Stagnara [9] proposed and substantiated the choice of the so-called plane of the true deformity (plan d'election) determined by rotating the trunk in the horizontal plane to display the most pronounced deformity, while rotating in the opposite direction displays the least pronounced deformity. Other authors have proposed ways of measuring rotation, e.g., a popular Nash – Moe method [10] that is based on measuring the vertebral pedicle shadow on anteroposterior radiographs. The systematic use of anteroposterior and lateral radiographs for scoliosis began only in the late 1970s. A special case is represented by patients with severe kyphoscoliosis whom we described together with Mme Duval-Beaupere in 1972 [11]. This is the so-called progressive rotational dislocation of the spine – rotational kyphosis between two lordotic segments. It can develop at any level, but always between two lordoses. If the transitional zone between lordoses contains several segments, it is shaped as a "siphon"; if there is one segment, the transition becomes more angular. The latter situation often occurs in dystrophic deformities (NF 1) or degenerative deformities in elderly patients.

This was the time when I tried to optimally visualize a 3D reconstruction of the scoliotic spine, which was implemented in a study "Paralytic pelvic obliquity" describing the "pelvic vertebra" concept [12]. It should be remembered that the main theme of the Montreal meeting of GES (1979) was "idiopathic scoliosis in the sagittal plane", and this theme was chosen precisely to draw attention to the three-dimensional nature of scoliotic deformity.

The accuracy of an axial rotation measurement technique was significantly improved by Rene Perdriolle and his torsiometer; the technique was based on anteroposterior radiographs (Fig. 2). In the book "Scoliosis, a three dimensional deformity" [13], Perdriolle demonstrated that measurements in the horizontal plane should focus not only on the main curve where the maximum axial rotation is observed but also, and perhaps even more, on the boundary between two curves where the rotation reverses direction, as described and illustrated in the book by Adams nearly 100 years ago. Perdriolle termed it "specific rotation" and considered it as a predictor for a group of patients with infantile scoliosis, thereby confirming the value of another predictor for the same group of patients. This refers to the "costovertebral angle" described by Min Mehta; this technique also demonstrates importance of changes in the horizontal plane for the pathogenesis and evolution of scoliotic deformity.

Acquaintance and collaboration with Henry Graf, as well as with developers of mathematical models and software (in particular, Jerome Hecquet) from the Pompidou Center Museum of Modern Arts in Paris in 1977 led to the development of a real 3D computer reconstruction of the scoliotic spine [14] based on the use of two orthogonal radiographs of the same patient. Even a primitive linear image based on landmarks on the vertebral bodies demonstrated its three-dimensionality when looking at the model from its apex and confirmed importance of changes in the horizontal plane. The next stages included work with simple schematic planar models of each vertebra and then with volumetric ones, which provided a gradual approach to real anatomical specimens obtained from cadavers of scoliosis patients who died from various causes. The emergence and development of CT scanning enabled assessment of direct changes in the horizontal plane, despite some confusion at the beginning. This refers to some discrepancy between a single slice and the real picture created by a set of sequential slices of the entire curve and entire spine. However, this approach was considered unacceptable due to a significant exposure dose required to achieve the goal, especially in children and young adults, because there was evidence of an increased risk of cancer caused by such cumulative doses.

For me, this was one of the reasons why, in the early 1980s, I started collaborating with a group of engineers (Francois Lavaste and Wafa Skalli) from the Biomechanics Laboratory at the Ecole National Superieur des Arts et Metiers (ENSAM) to create a 3D computer model of the scoliotic spine using the finite element method and two orthogonal radiographs. The obtained data were confirmed, of course, by a similar reconstruction based on investigation of real anatomical specimens of the scoliotic spine provided by the University Pathological Anatomy Laboratory.

Undoubtedly, all this was the reason for me to start collaboration with the Georges Charpak group, which led to the development of the EOS imaging system (1998–2000) that, in my opinion, provides the best opportunity to investigate changes in the horizontal plane in scoliosis with the patient in a standing position, using the minimum radiation exposure (Fig. 3) [15].

4. Biomechanical demonstrations, considerations, and simulations certainly reinforce the concept under discussion. Many years ago, Lewis Sayre (1877) in the USA created a model of the scoliotic spine [16]. It was a rectangular frame with fixed dry specimens of thoracic and lumbar vertebrae positioned in a natural way. Each vertebra was fixed to the frame by the transverse processes using elastic rubber bands symmetrically on both sides. The result was an excellent symmetrical alignment of the vertebrae in the frontal and sagittal planes. A semi-rigid brass rod was inserted into the vertebral canal of the whole spine model; there was a button at the upper end of the rod. Pressing the button caused the formation of a typical double scoliotic deformity due to horizontal forces applied by elastic bands. When the button was pulled up, the deformity disappeared.

Another, more recent, model was developed based on mathematics and biomechanics methods at the ENSAM in Paris. The model was used to demonstrate that vertical pressure on the head (increasing longitudinal load on an optimally aligned straight model of the spine) never causes the development of scoliotic deformity, but upon introduction of intervertebral axial rotation into the model, the same load leads to the development of scoliosis. These data fully correlate with the recent (2019) results of Rene Castelein from Utrecht [17] who demonstrated in anatomical, radiological, and biomechanical studies that the development of scoliotic deformity of the spine requires a transverse (horizontal) component of deformity mechanogenesis.

Fig. 2
Measurement of axial rotation with a Perdriolle torsiometer

5. There are many arguments in favor of the concept, which are based on assessment of the spine condition before and after treatment (conservative and operative). The first argument is an understanding of the nature of kyphoscoliotic deformity. Outwardly, kyphosis always has a greater or lesser scoliotic component, but careful examination of two typical projections shows that if the apices of both deformity components (kyphosis and scoliosis) are located at the same level, we are dealing with pseudo-kyphosis (called paradoxical) that is secondary with respect to very important axial (horizontal) rotation. On the other hand, if the apex of a kyphotic deformity projection lies at the level of transition between two scoliotic curves on the frontal radiograph, it is a true junctional kyphosis. A case of this kyphosis was observed during surgical correction of S-shaped scoliosis using a Harrington distractor, when the rod was located on the concave side of each scoliotic curve, and junctional kyphosis coincided with the shadow projection of the rod.

The opportunities of practical application of the concept to the clinical practice were presented at the SRS meeting in Chicago (1980) when the course of infantile idiopathic scoliosis was predicted based on assessing deformity from the top. This might have been used to develop an ID card analogue, but, unfortunately, was not understood by the orthopedic community.

Another clear evidence is the crankshaft phenomenon [18]. It is excellently visualized by 3D reconstruction when the spine is evaluated from the top to bottom. When we look at this simple model, it is impossible to refute the "concept of physiological and biomechanical stack" of vertebrae in scoliosis. Later, the crankshaft phenomenon was widely recognized.

A well-known rotational maneuver underlying the Cotrel–Dubousset instrumentation technique is based on movement of the rod in the horizontal plane, although its visual consequences appear in the frontal and, to a greater extent, sagittal planes [19]. I would like to emphasize once again that it is the horizontal plane where the derotation is performed.

Conservative treatment of scoliosis with plaster or removable casts for achieving correction also uses action in the horizontal plane. For example, correction with a plaster cast using special EDF (Elongation, Derotation, Flexion) casting involves the so-called derotative straps. In the case of two structural deformities (right-sided thoracic and left-sided lumbar), right-sided thoracic and left-sided lumbar straps act in opposite directions in the horizontal plane and can be supplemented by a left-sided shoulder strap.

The development and description of the Spinal Penetration Index concept [20] as well as the classification of four hump

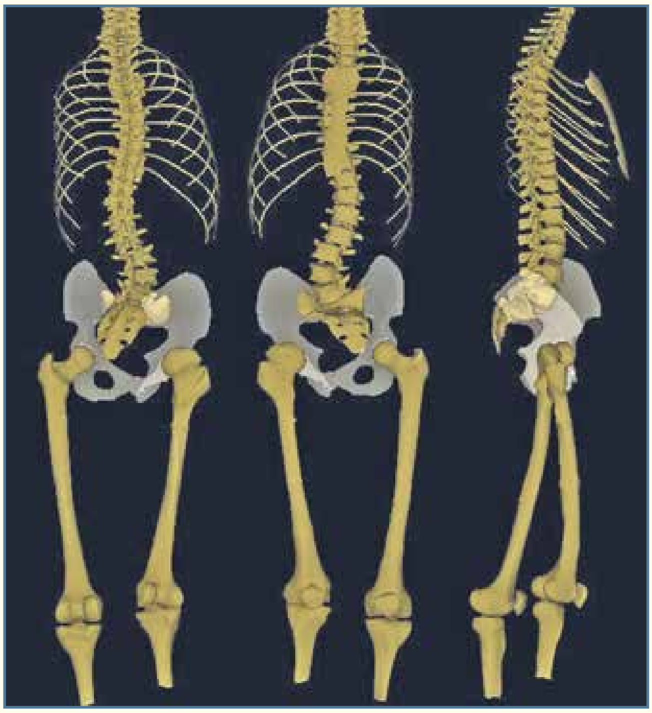

Fig. 3
EOS imaging of the spine

types in scoliosis are entirely based on the role of the horizontal plane in the deformity mechanogenesis (Fig. 4).

Modern cast systems are based on the use of horizontal corrective impacts, rather than on lateral or posterolateral pressure and counter-pressure.

The development of the EOS imaging system provided two new rationales for significance of the horizontal plane concept:

a) the deformity severity index developed at the ENSAM enables predicting progression (or stability) of deformity. Its measurement is based mainly on deformity parameters in the horizontal plane: torsion index, apical rotation, intervertebral rotation at the upper and lower ends of the curve, apical lordosis, and Cobb angle. All measurements are performed quasi-automatically, and the resulting prognosis has a confidence level of 89 % (Fig. 5).

b) "vertebral vectors" [21] were developed by Tamas Illes to facilitate visual assessment and measurement of the stack of vertebra in the horizontal plane. These vectors are projected onto a horizontal plane and are used for a three-dimensional classification of deformity, assessment of the balance and outcomes of any type of treatment, and in some difficult cases help formulate indications and choose a treatment option (Fig. 6).

Given all these reasons, we believe that for scoliotic deformity of any type and etiology, the horizontal plane is "main" (if not the reference point), even if the plane was not actually "forgotten" [22] but only "set aside" a little, probably due to visualization difficulties. Nowadays, 3D reconstruction with the patient in a standard functional position becomes more and more available, and I believe that this will lead to new studies.

What are the optimal clinical and imaging technologies that help solve the discussed problem, in particular in quantitative terms?

The first is to look and think! In this case, clinical examination begins with evaluation of patient's gait, with mental and visual assessment of the opposite movements of the shoulder and pelvic girdles. Then, the patient is examined in a sitting position on a chair, with examination from the top to the bottom (the doctor's eyes are above the patient's head), noting the orientation of the shoulder girdle and pelvis as well as the position of the scapulae and apex of the rib hump.

Use of simple tools (scoliometer) to assess the humps corresponding to the primary and secondary curves. Further, if a surface topography system [23] is available, it enables assessing the shape of a horizontal contour along the entire spinal column, including the pelvis. If the patient with pelvic obliquity is unable to walk, it is possible to measure the shape and size of an imprint of the buttocks and thighs on the plane on which the patient sits. In my opinion, this is the most accurate method for assessing the position of the pelvis in deformities of any etiology, both before and after treatment (conservative or surgical). The method better reflects the achieved outcome compared to the Cobb angle that demonstrates only a frontal projection of the spine.

Unfortunately, for so many years, the 3D concept of spinal deformities has not been implemented in daily practice as well as textbooks and publication requirements of top-ranked journals, in contrast to the "gold standard" the Cobb angle. Importance of changes that occur in the horizontal plane and are reflected in the three-dimensional structure of a deformed spine is not widely understood.

That is why the EOS imaging system is now the best computerized 3D reconstruction technique that provides the maximum information on a deformed spine in a standing and sitting position. Of course, this is a static but three-dimensional examination. Examination in the horizontal plane, from the head to the toe (or in the opposite direction), with measurements in accordance with the concept of vertebral vectors, is extremely informative before and after surgical correction of any scoliotic deformity, but it is especially illustrative in elderly patients. The unique opportunity to examine the spine in a horizontal projection (from top to bottom) enables measurements of lateral and anteroposterior deviations and axial rotation, not only for a single spinal segment but also globally, level by level. In addition, this technique allows for easy visualization and measurement of intervertebral axial rotation, which is extremely important for identification of potentially unstable transition regions (Fig. 7).

Many researchers have developed dynamic 3D examination techniques using combination of 3D landmarks recorded during movement and a static reconstruction provided with an EOS machine. The system also enables examination of the center of body mass gravity. The results of all studies are evaluated in combination with measurements of masses of various body parts (head, head and shoulders, upper trunk, lower limbs, etc.). In addition, it is necessary to consider the speed of movement (assessed with a simple chronometer) to solve the tasks set during initial examination in the advisory office. We should measure the time taken to walk 4 to 5 steps back and forth, climb up and down three steps, squat and stand up (perhaps, the most discriminant) and, finally, for a dual task assessing the patient's cognitive functions to walk a few steps back and forth while talking on the phone or counting down aloud. All these active measurements are included in the examination of any patient, regardless of deformity etiology and planned treatment, conservative or surgical.

The last point where the horizontal plane plays the most important role is examination in terms of the harmony concept. Obviously, the harmony of any movement (walking, running, throwing, etc.) depends to a certain extent on adjustment of any joint involved in this movement in the horizontal plane. When observing and 3D measuring the mechanism of lower limb movement, starting from the contact of the foot with the ground, we note that movement in the horizontal plane occurs at each successive anatomical level, starting from the skin on the plantar surface of the foot, then the subtalar joint, the ankle joint with movement of the talus within the tibiofibular fork, well-known rotational adaptation of the knee joint, and, finally, the hip joint with the changing orientation of the pelvis at each step. The same thing happens at any movement of the upper limb. Movement in the horizontal plane provides smoothness and aesthetics to each motion act, making it harmonious.

When we see a walking or running person, anyone can at a glance distinguish between harmonious and disharmonious movement. Paul Bellugue [24], a former professor of anatomy at the cole des Beaux-Arts in Paris, gave a fine definition of harmony for human nature (see below). In orthopedic "language", harmony balances the "gold standard of the Cobb angle".

We know very well that:

– harmony in music is consonance of different tones, and this is ultimately the law of physics (the opposite is dissonance of sounds)!

– harmony in visual arts is consistency in the arrangement of successive color combinations (the opposite is color slashing).

In reality, the classification of harmony from the standpoint of human nature or function is complicated by a subjective factor that varies depending on education, traditions, and historical past that is why so little has been done to include these concepts in assessing the patient's condition before and after treatment. But we must think about it! Here is the definition formulated by Paul Bellugue: "Harmony of the movement is the right distribution of the masses of the body cephalic, thoracic, abdominal, pelvic, hanging above the lower limbs on the move". He also owns the phrase that confirms my concept of the "cone of economy": "Harmony is the sister of economy". Therefore, harmony exists for "small and large people", "even and angular shapes", light and heavy people, well and poorly built people, and changeable and balanced movements.

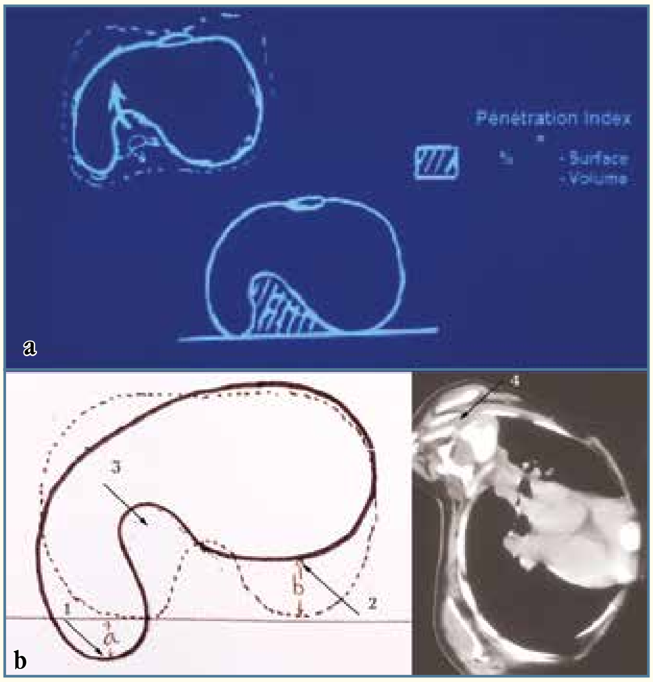

Fig. 4
Spinal Penetration Index developed by Dubousset **(a)** and four hump types in scoliosis **(b)**: *1* – exothoracal (classic type) with a bulge on a convex side of the curve; *2* – exothoracic on the a concave side of the curve; *3* – endothoracic (protrusion of the vertebral bodies); and *4* – due to endolateral thoracic protrusion of the vertebral bodies

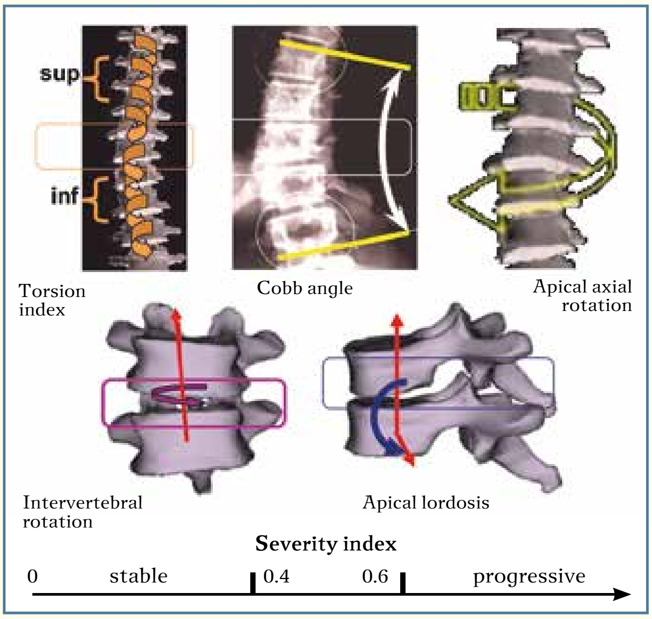

Fig. 5
The prognosis of mild idiopathic scoliosis at the first examination (89 % reliability)

Ultimately, regarding the spine, the concept of harmony implies:

1) smooth 3D alignment in height and weight;

2) an acceptable distribution of body part masses, from feet to head;

3) 3D static balance within a small cone of economy;

4) 3D movements within normal functional baseline ranges.

We are far from the “gold standard of the Cobb angle”, and it will take a lot of work to develop a reliable and scientific classification in this field of science, but I am sure it is necessary.

How does the proposed concept affect the choice of strategic and technical tasks in conservative and surgical treatment of scoliosis patients?

One of the most important variants of concept applications is assessment of the severity index of scoliotic deformity, especially in small (at the stage of development) deformities in children in the prepubertal period or close to it and as early as possible full treatment with a plaster or removable cast to achieve the best outcome and prevent, if possible, surgical intervention. The accuracy and reliability of predicting the severity of disease using this index amount to 89 %, with calculations being made almost automatically using conventional orthogonal radiographs done in the EOS imaging system [25]. It is important to emphasize importance of correct patient positioning in the EOS booth.

Reconstruction of the spine, as well as the chest, in the horizontal plane enables. Quantitative evaluation of the outcomes of cast therapy, namely: correction of spinal deformity and balance of the trunk with and without a cast; the chest shape and the result of excessive pressure on the rib cage. Using these data, the attending doctor can immediately ask the cast technician to modify or even completely rework the orthosis.

On the other hand, a similar situation can stimulate the surgeon and engineers to contemplate, invent, and develop new

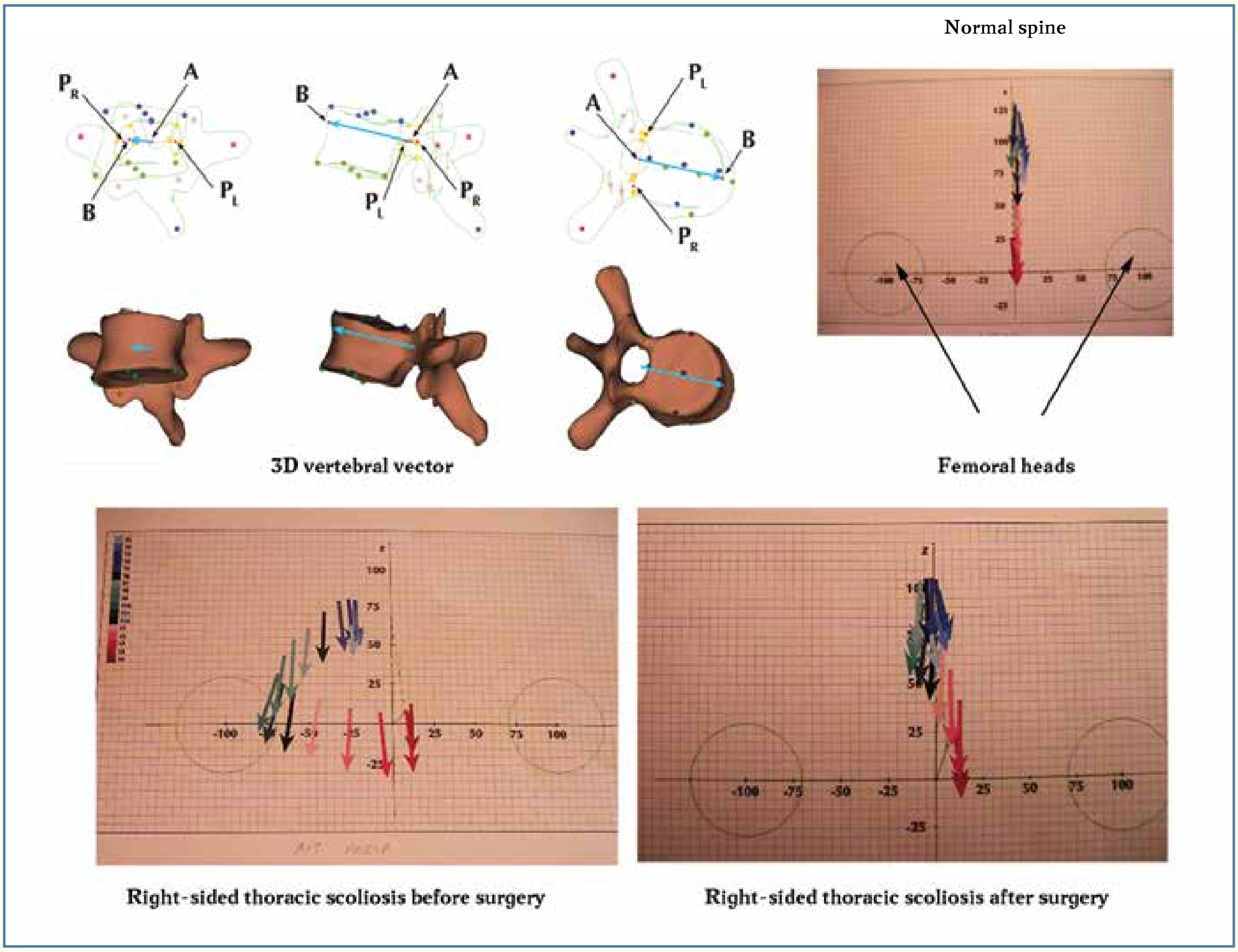

Fig. 6
Vertebral vectors were developed by Illes [21] to facilitate visual assessment and measurement of the stack of vertebral bodies in the horizontal plane

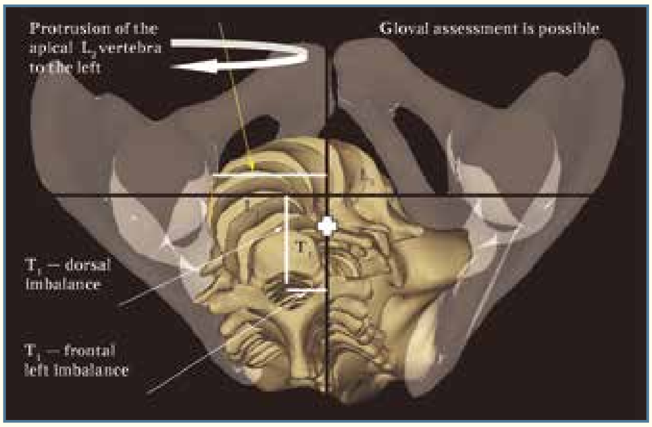

Fig. 7
New tool for analyzing the shape of the spine determining the gravity projection axis: the position of each vertebra can be estimated separately

casts with new goals: without pressure and counter-pressure on the chest and spine, but with the possibility of counter-torsion in the horizontal plane using, if possible, the respiratory muscles.

Surgery should be planned with regard to the importance and role of the horizontal plane. Determination of the length of instrumented fusion and bone grafting area. The horizontal plane again comes to the fore: in fact, the main issue is the difference between structural and compensatory deformities. Many surgeons assess only the Cobb angle in lateral tilt or axial traction radiographs; but in my opinion, the most important thing is to understand what is happening in the horizontal plane. If the rotation is completely eliminated, the compensatory curve does not need to be included in the fusion area. If there is no or little detorsion, or even total axial rotation persists, this is a structural curve that should be blocked completely to prevent 3D imbalance.

When the "pelvic vertebra" is the last vertebra of the scoliotic curve and is rotated horizontally in the same direction as the lumbar curve, it should be included in the fusion area. But if the "pelvic vertebra" and the lumbar curve are rotated in opposite directions, the pelvis should be considered as a small compensatory curve and, in terms of long-term outcomes, should not form a block with the spine.

Identification of unstable zone is performed using signs present on anteroposterior and lateral radiographs as well as on functional images (traction or lateral tilt). Reconstruction in the horizontal plane provides qualitative and even quantitative information not only on the rotation orientation but also on the rotation magnitude, which makes rotational dislocation predictable and helps determine the position of the upper and lower instrumented vertebrae. The conclusion is simple: never start or end the fusion area at an unstable vertebral level.

Computer simulation of surgical intervention is another option for using the horizontal plane when determining the length of the fusion area. In this manner, it is easy to simulate the surgery outcome by changing only one level of the upper or lower end vertebra. This is a widely used technique for choosing a treatment approach based on the spinal sagittal contour and pelvic parameters, but sometimes there are failures due to ignoring spine condition in the horizontal plane.

Therefore, we strongly recommend engineers and the surgical community to include everything related to the horizontal plane in the analysis of the situation.

Why does this concept provide a new approach to assessment (in particular, quantitative) of the patient's condition before and after treatment in both 3D visualization and functional terms? This is assessment before and after any, but primarily surgical, treatment. Despite the fact that assessment of anatomical changes in scoliosis in most cases is based on measuring the Cobb angle (in frontal and lateral projections), we believe that 3D examination including the horizontal plane, spinal balance, and analysis of movements is a more reliable and reproducible approach because measuring the Cobb angle enables assessing only the degree of spine collapse. Furthermore, since the lower limbs are involved in 3D posture organization, it is necessary to consider the effect of their length on the spine condition. This was perfectly demonstrated by Isidor Liebermann [26] who quantitatively investigated the "cone of economy" concept by measuring a displacement of the ground projection of the patient's body gravity line (Fig. 8), and by Kazuhira Hazegava from Japan [27] who measured ground projections of various elements of the patient's body chain of balance, including the head (Fig. 9). We may say that the spinal surgeon community has well accepted the idea that the long-term prognosis of spinal deformity (treated conservatively or operatively or untreated at all) depends on the dynamic 3D balance of the vertebral segments caudal and cranial to the blocked or instrumented area. As Alain Dimeglio said, maximal correction is not always optimal. Modern equipment and instrumentation designed to correct spinal deformities take into account the significance of what occurs in the horizontal plane at the global and segmental levels.

Of course, we should remember that all these biomechanical speculations and considerations should always take into account neurological status of the patient, both in neuromuscular (balance problem) and in cognitive aspects.

Conclusion

We should understand and remember that scoliotic deformity (idiopathic, paralytic, degenerative, etc.) is a compensatory response in the chain of balance to a rotational phenomenon in the frontal plane. Our goal is to achieve balance of the patient's body in a standing, sitting, and even lying position through understanding its three-dimensionality and realizing the importance of horizontal plane consideration. This goal should always be remembered when choosing a treatment approach for the patient with scoliosis of any etiology, and this will lead to success.

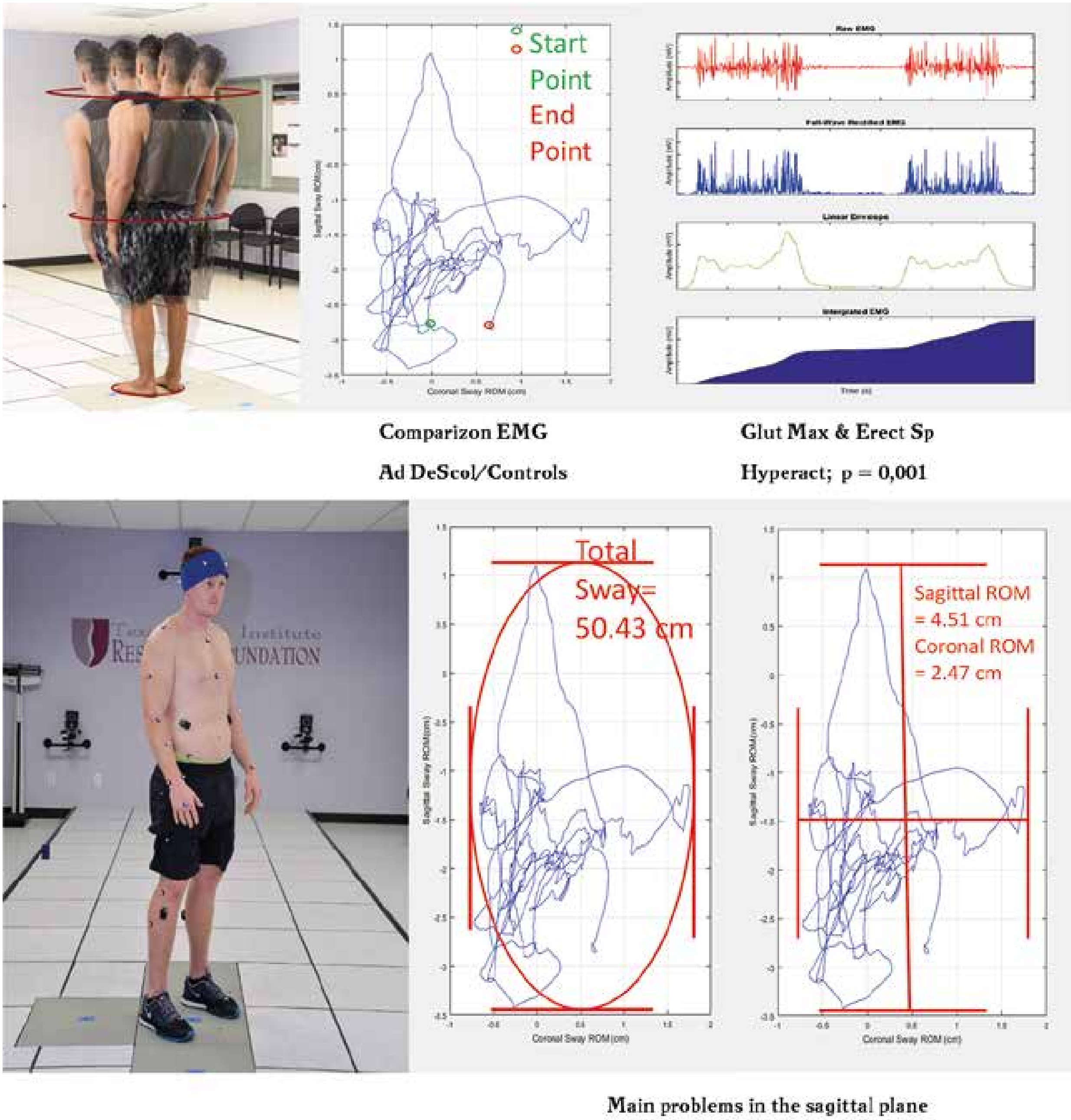

Fig. 8
Quantification of the economy cone according to Lieberman [26]

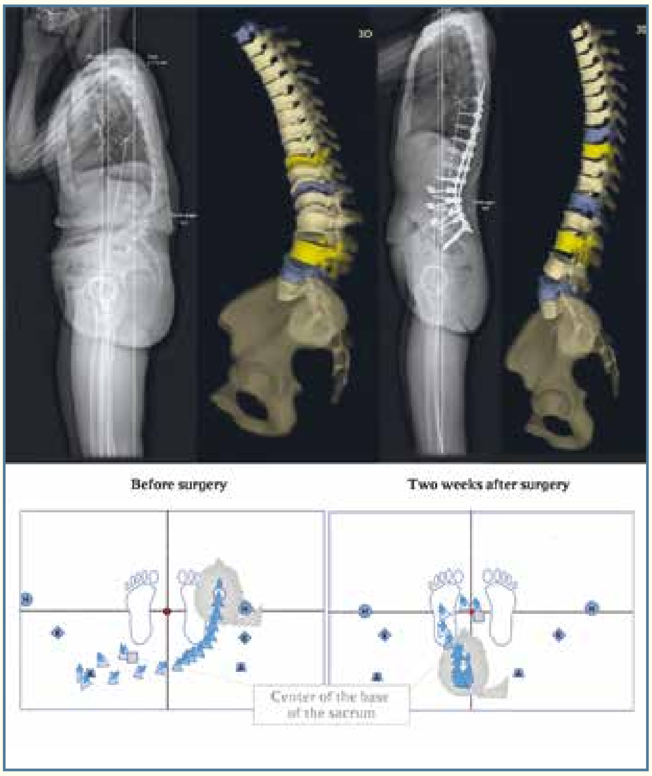

Fig. 9
Vertical projection onto a horizontal plane (courtesy of Hazegawa): comparison of torso alignment before and after surgery [27]

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