

## Review Article

# Spinal Alignment, Balance and Harmony through the Ages

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## Introduction

Most of the studies about the alignment of the body and subsequently the spine are based on static considerations reported through clinical and mostly radiological views Frontal and Lateral in standing position. From the last 25 years the measurements were done almost exclusively with angles exploring of course the frontal plane with the Cobb angle and mainly the sagittal plane projection of the various segments of the spine including pelvis, with also the Cobb angle principles. This drive to angular formulas comparing patients without deformities considered as normal and those with deformities. The consequences of this almost univocal approach were that the planning of the surgical corrections was done on a purely angular goal. This results in a subsequent extension of the fusion/instrumentation areas and too frequent failures either with the severe flattening of the back or with so called Proximal junctional kyphosis resulting in immediate or late deterioration of the balance and functional results of the patient.

## To Study and Understand the Development of this Paper, 4 Basic Concepts Must be Understood & Accepted in 3 dimensions (3D) at Any Age

### First concept

To Study the Spinal Biomechanics the Segmental Masses areas and probably more important than the Angles, because we must not forgot the horizontal plane deformity well seen in developmental Scoliosis in children or in degenerative de novo scoliosis in the adult. This pushes us to think Masses instead of angles (Figure 1).

### Second concept

The chain of the alignment at the level of the trunk is made with a piling up of globally 28 masses with variable sizes and weight, with the heavy Cephalic vertebra (entire head) at the top and the pelvic vertebra (entire pelvis) at the bottom. This one, playing the role of an intercalary bone for an adaptable posture between spine and lower limbs skeletons.

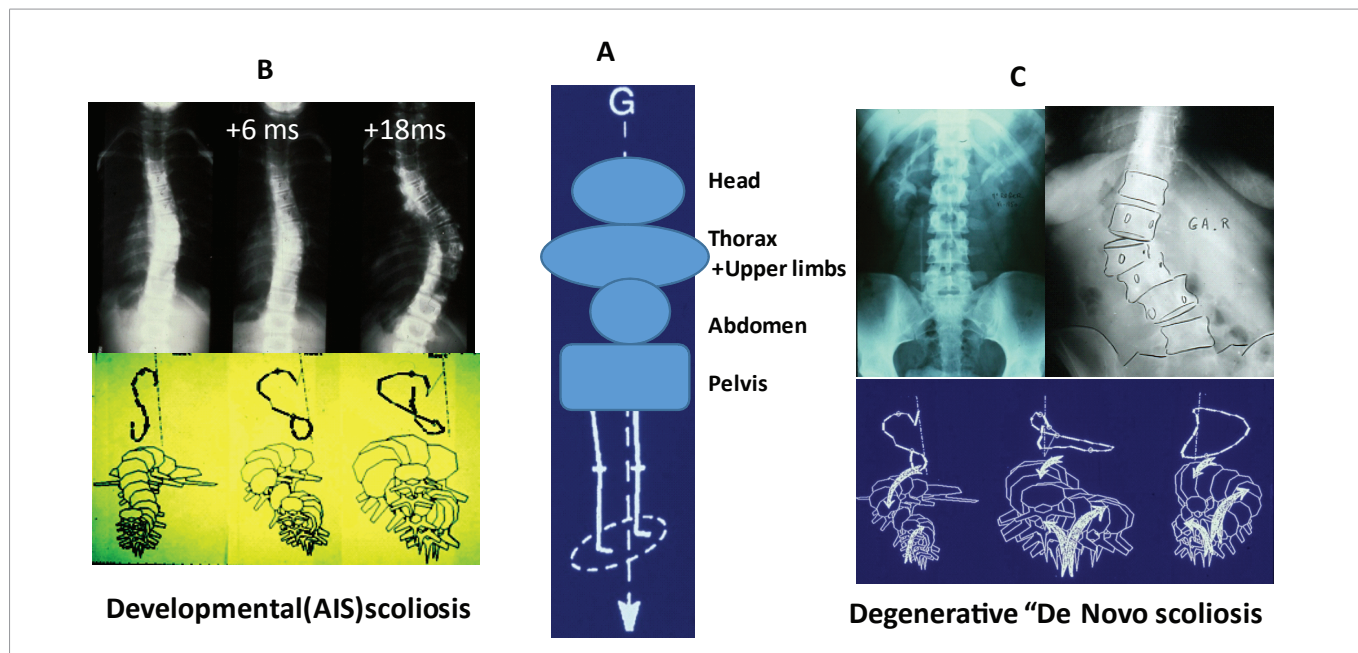
This Chain of Alignment successively starts from the 2 plantar soles of the feet and continue with the skeleton and joints of the subtalar then ankle joint, tibiofibular skeleton, knees femurs, hips joints, pelvis and the 24 vertebrae and intervertebral joints. It ends with the entire head playing the role of cephalic vertebra. All these segments are aligned with at the level of the spine a straight projection in the frontal plane and a harmonious sagittal plane projection with successive lumbar lordosis, thoracic kyphosis, cervical lordosis and positioning of the head in order to get an horizontal gaze. The chain of Balance of the body is exactly the same, but working either in standing or in sitting posture like a reverse pendulum (oscillating structure with the weight at the top), because the erect posture in human is never completely immobile but present a small 3D oscillation well detected by the recording of the center of pressure of the body on a force plate under the feet.

### Third concept

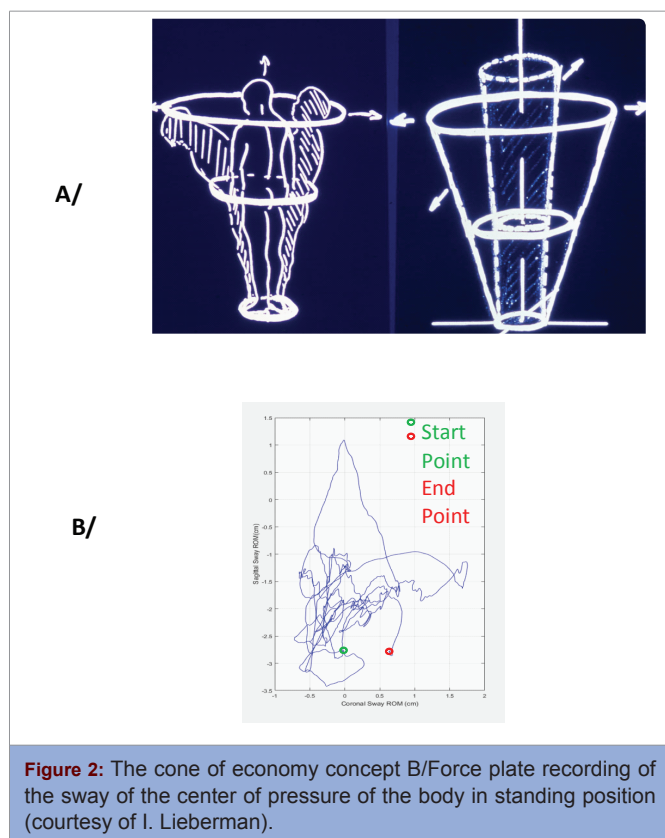
These 2 chains coincide but it is only necessary to not confuse Alignment which is static and Balance which is Dynamic.

### Fourth concept

Cone of Economy (Figure 2) where these bone and joints



**Figure 1:** (A) The Chain of Balance and the Chain of Alignment coincide but alignment is static and Balance is dynamic The Masses of the segments of the body are more important than the Angles as demonstrated by the 3D reconstruction of scoliosis seen from the top either developmental in an adolescent (B) or De Novo in an adult patient (C).



**Figure 2:** The cone of economy concept B/Force plate recording of the sway of the center of pressure of the body in standing position (courtesy of I. Lieberman).

axial structures with their surrounding mass of variable tissues or appendix (upper limbs) remain in the “small cone” area using a minimum of muscle power to stand as they use much more when they are outside the small cone during motion or exercises. This

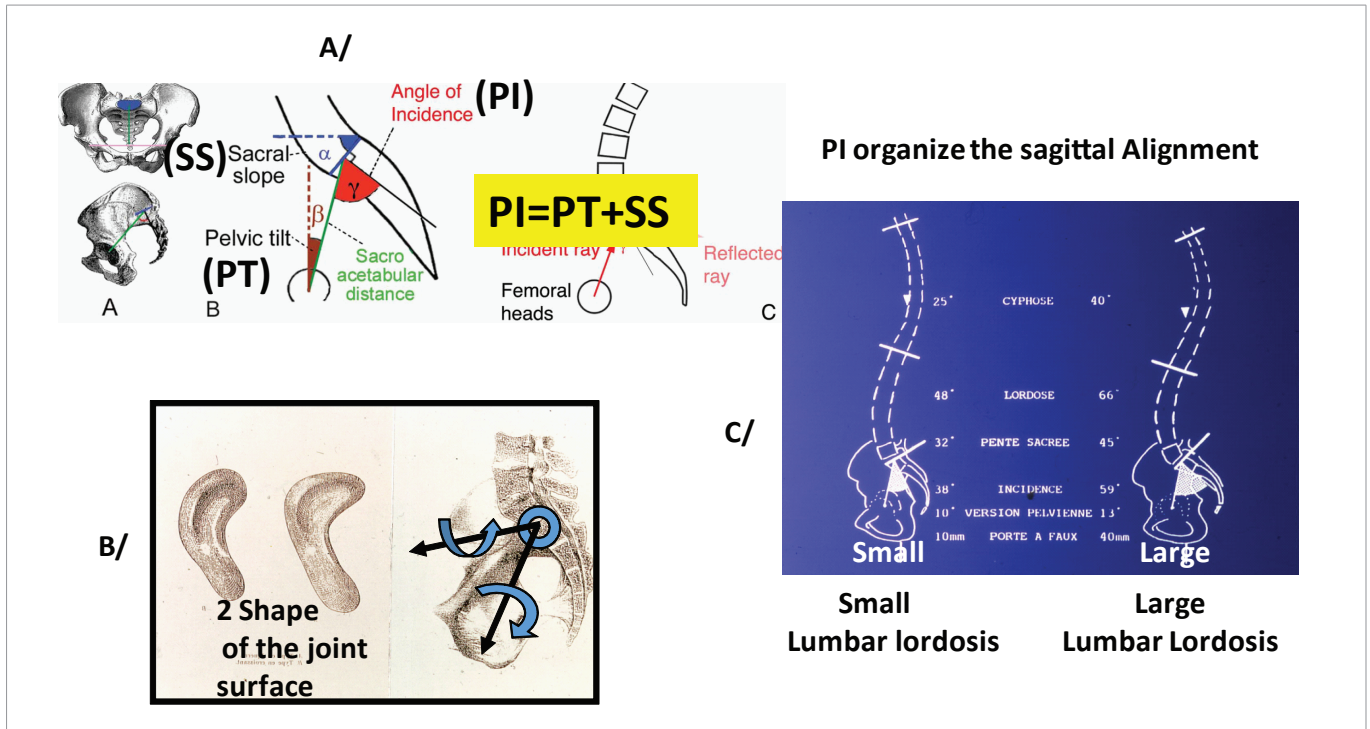
concept explain the phenomenon of Compensation or adaptation of the posture (especially at the level of the lower limbs) in order to try to maintain the body within this “economical” small cone. This was well demonstrated with the recent work of Isidor Liebermann trying to quantify the Cone of Economy concept [1].

### Acquisition of the Erect posture in Human

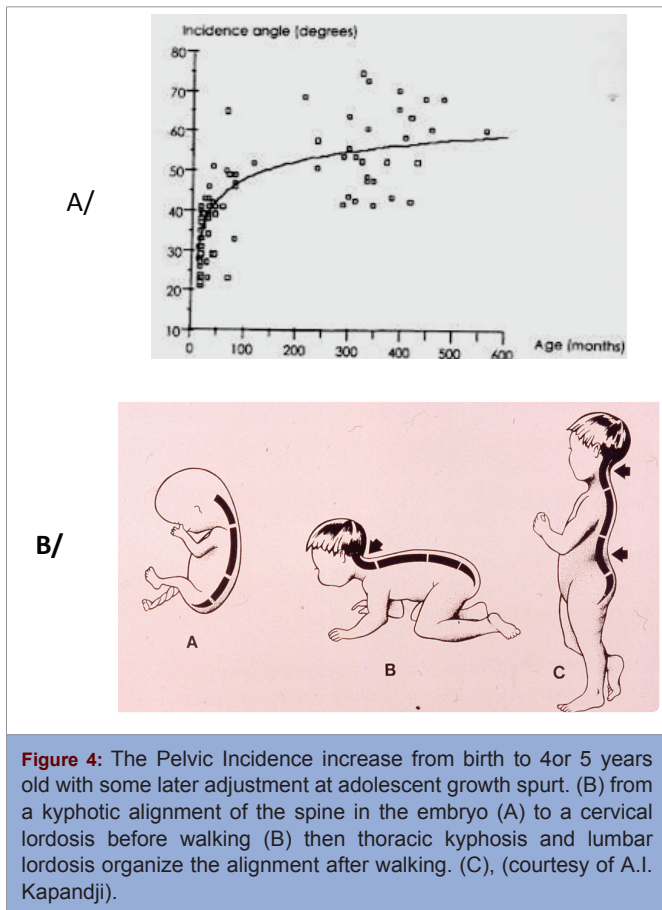
Alignment and erect posture are acquired progressively during the 10 or 15 first months of life, but the refinement is only obtained at the end of the stature and neurological maturation as demonstrated by François Clarac [2], at the cephalic vertebra level with the goal to get an horizontal gaze.

Anthropology help us to understand the relation between the cephalic vertebra and the erect posture: Comparing the position of the foramen magnum in quadrupedal, the foramen magnum is located on the head Posteriorly in continuity with the spine Chimpanzé - Australopithecus, Pithecanthropus - Homo sapiens: More the hominides became bipedal, more the foramen magnum become central under the skull.

At the pelvic vertebra level with the relationship between the pelvic parameters (especially the incidence angle) described by Mme Duval Beaupère [3] and the amount of lumbar lordosis & thoracic kyphosis (Figure 3). In utero and at birth the alignment of the spine is in kyphosis with a small incidence angle. But it was found also very variable incidence angles even in embryo demonstrating the reality of a genetic factor but also the influence of the hip flexion on the shape of the pelvis. With the acquisition of the erect posture the incidence angle increase (Figure 4) as establish lumbar lordosis and increase also. The pelvic version or pelvic tilt, is also apostural parameter, evolve according the formula Pelvic Incidence = Sacral slope + Pelvic tilt. So we can postulate that the pelvic incidence organize the sagittal



**Figure 3:** (A) The pelvic Incidence angle is an anatomical parameter with the formula Pelvic Incidence equal Sacral Slope (SS) + Pelvic Tilt (PT). (B) The Pelvic incidence angle shows the rotation in the space of the Sacro iliac joint components C/ The Pelvic Incidence organizes the sagittal alignment of the spine.



alignment of the spine. Again, anthropology helps us: the Incidence angle increased from Australopithecus to Human sapiens as bipedalism became dominant. We can conclude that the erect posture in humans is the result of a harmonious alignment of bones and joints lasting during motion thanks to a neurological input-automatic-reflex-modulated & voluntary - it is Balance. Biomechanical and neurological organization of alignment from birth to adult [2].

From birth to 14 months, the organization is descending within first the cervical lordosis followed by stabilization of the pelvis obtained after 2 months of free standing posture. Up to 6 years old, the organization is ascending from the stable hips, Head & Shoulders function are « en bloc ». Within 7/8 years old, descending organization of the balance with vestibular dominance, the Head in space recovers its own motion regarding the shoulders. From 8 to 13 years old, the organization works in both directions close to the adult one with a complete dissociation Head - Trunk.

**The Alignment of the Bones, Joints and Soft Tissues of the Spine will develop simultaneously in 3D as for Growth and Maturation**

With its specific velocity and the noticeable Growth Spurt, with also the development of the thoracic cage and lungs volumes continuing in width for 2 years after end of standing growth in height. Spinal sagittal alignment changes from early childhood to adolescence & adult. Because of morphological reasons, for the cervical spine and head posture between 3 years old to adult, the protraction of the head decreases, but also C2-C7 lordosis decreases and O-C2 and C1-C2 increase, with a maximum of lordosis in C1/C2.

For the thoracic and lumbar spine following the pelvic morphology the incidence angle varies from 22° to 86° and the subsequent sagittal shape according the Pierre Roussouly [4] classification follow the rule small incidence coincide with a small lumbar lordosis and thoracic kyphosis with the Type 1 and 2 and large incidence coincide with a large lumbar lordosis and thoracic kyphosis with the type 3 and 4. Most of the final alignment is acquired by age 9 or 10 y old with some adjustment at the growth spurt period. Then from adult to Aging, pelvic incidence increase also slowly especially after 65 y old [5-7] with of course their subsequent spinal alignment changes. This demonstrate the plasticity of the Sacro Iliac joint as it was already proven [8] after change in the incidence angle secondary to a spine fusion for scoliosis at the thoracic level (Lower instrumented vertebra above L2) in 50% of a cohort of an adolescent female group. Because postural reasons, Osteoporosis often results in global or localized kyphosis, it is why Minimal invasive vertebroplasty with cement give frequent good results for pain and sometimes stabilization. Ante-version and retro-version of the pelvic vertebra demonstrate the major role of the pelvic vertebra in the compensation mechanisms for the posture, with a special attention to the motion of the hips joints especially thanks to the "hip joint reserve in extension" described by Isvan Hovorka [9]. Alignment and Balance are permanently linked, the result is the stability within the movement driving to Economy.

## What are the Requirements for Balance

### Mechanical requirements

A proper mobility of the joints, within a safe alignment chain in space. In ageing people osteoporosis often results in global or localized kyphosis, it is why Minimal invasive vertebroplasty with cement give frequent good results for pain and sometimes sufficient stabilization to recover balance.

### Tensegrity of aponeurosis, ligaments, the "White structures" surrounding the muscles [10]

It is the quality of these elements on their Tension/Compression biomechanical role often ignored and giving an "Energy" release factor". Muscles agonist and antagonist requirements are with their strength, Power, Relaxation, Modulation, Speed, Acceleration, Braking. Neurological requirements at the different levels of the Afferents inputs: Vision, Vestibule, Proprioception of the Modulation, Coordination, Automatism, Double task = Cognition well explored with the functional Magnetic Resonance, and of the Effectors outputs: Order, speed of transmission, Time of reaction. All these functions create a composite chain in the space ordered by neurology.

Ageing touch also all spinal structures as for bone as for soft tissues (capsules, ligaments, muscles, nerves, brain, leading to 3D change in the Alignment and Balance where compensation is the "magic word" for posture. The compensation phenomenon can occur at any levels of the chain of balance on the anatomy, thoracic, lumbar, cervical, pelvic, lower limbs, If remains a sufficient flexibility, and you immediately understand that extensive fusion reduce the compensation possibilities. But also compensation phenomenon can occur on a neuro muscular basis (any levels at any age) as demonstrated by the good results of active exercises). This gives often a sufficient factor to allow long duration of an acceptable function. But sometimes the neurological central degeneration don't allow such

possibility. It is why the estimation of the Cognition is a major test to measure the functional status of the patient during aging evolution and of course mandatory in a preoperative check-up (The dual task test being very useful). The common influence of pelvic and cephalic vertebrae posture with ageing was well described in the literature with the Protraction/retraction of the head combined with the pelvic retroversion. The 3 key words for the goal in the treatment of spinal deformities are Alignment and Balance driving to Stability during the movement resulting in the concept of Economy to achieve posture as well as function on the Chain of Balance of the body (Figure 5).

### Subsequently: Alignment in 3D results from Genetic and Biomechanics with various shape, size, height, weight and a common factor: Harmony

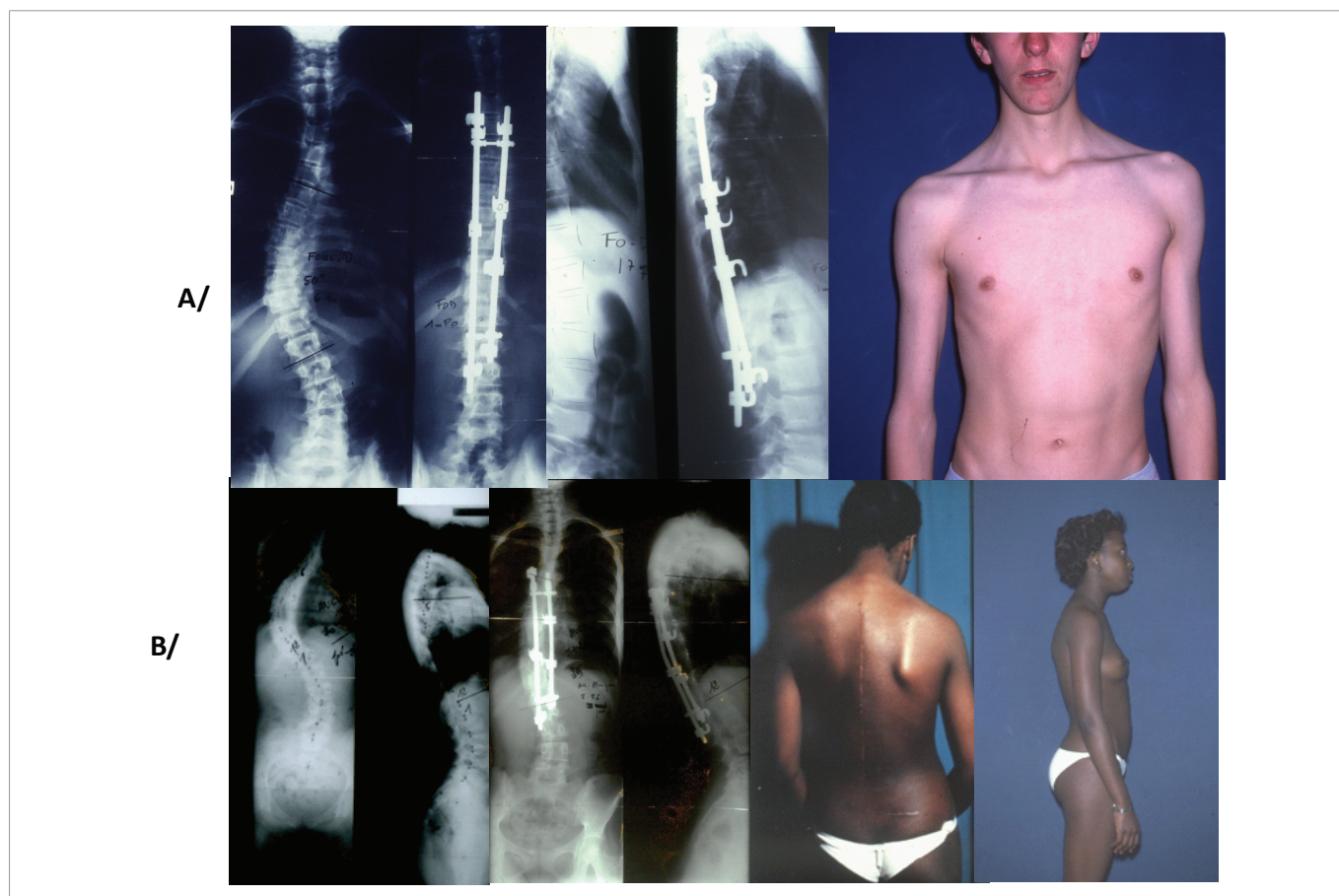
We must add to these conditions this word Harmony as it was defined by Paul Bellugue (1892/1955) who was professor of anatomy at the School of Fine Arts in Paris, when he said that "Harmony is the sister of Economy". [11]. For music, harmony is the concordance or agreement between the different parts of a tune, it is a real rule of physics. The contrary is discordance of a sound. For pictured arts, it is the accordance in the arrangement of successive colors. The contrary is clashing of colors. For spine and body for shape and movement "Harmony is the right distribution of the masses of the body, cephalic, thoracic, abdominal, pelvic, and hanging above the lower limbs". In reality this concept is difficult to classify, because it is subjective, variable according education, tradition, historical background. It is why very little was done to use it in Pre/post op evaluation of the results. For example (Figure 6) an Adolescent Idiopathic Scoliosis 60° Cobb angle corrected surgically to 0° on the frontal plane and no more than 10° appearance on the sagittal plane look not harmonious, when a similar case with the same initial angulation was corrected only to 30° with 30° appearance on the sagittal plane looks harmonious. The race to the best Cobb angle must not be the unique Goal. So we must think about. Human is harmony as well as for static posture as for dynamic activities. It is a good and pleasant, proportionate adjustment of the various parts of the body according size, shape, weight, alignment, movements. Subsequently harmony is observed for Short or tall size people, Smooth or abrupt shape, heavy or light people, generally well aligned people exceptionally mal-aligned, and finally demonstrating fluid and balanced movements. Harmony is a concept as for static as for dynamic conditions. It seems to me that for the next decades, harmony must be the goal to be achieved for the treatment of spinal deformities instead of the "Gold Standard" Cobb angle (Figure 7).

## Conclusion and Summary

Alignment, Balance and Harmony are always linked to achieve in the human spine the best economical function as in a static posture as during movements. This was acquired progressively during growth thanks to a genetic, biomechanical, and neurological control giving a fluid and harmonious function. Pathological or degenerative insults may destroy this beautiful arrangement, but the numerous possibilities of compensation mechanisms often suffice to maintain an acceptable function. When a surgical treatment requiring fusion is decided the goal must look to re-establish the harmony of the spinal organ leaving as much as possible the sources of compensation and flexibility above and below the fused area.



**Figure 5:** Alignment and balance drive to stability within the movement reaching the Economy thanks to Harmony which is the sister of economy.



**Figure 6:** (A) Adolescent Idiopathic Scoliosis reduced to 0° Cobb angle post operatively with shoulder asymmetry due to excessive correction and not harmony. (B) similar curve with less correction on the frontal plane but harmonious result with a 12 y follow up.



**Figure 7:** Adolescent idiopathic scoliosis treated with pedicular screws at every levels, despite important correction on the Cobb angle the spine is evidently not harmonious.

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