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Scoliosis

1. Scoliosis: application of physical principles

1.1 Etiological and biomechanical premises

The etiology of idiopathic scoliosis remains largely unknown despite decades of research.
Various theories have been proposed—genetic, neurological, biomechanical, metabolic, hormonal, and others—but none fully explains the phenomenon.
What is observed clinically is that curve progression is more rapid during pubertal growth and tends to stabilize, though not necessarily to stop, after skeletal maturity.
The biomechanical analysis that follows does not aim to explain the causes of scoliosis, but is limited to describing the vector mechanisms through which vertebral deviations manifest and can be interpreted from a muscular point of view.
The expression “and others” emphasizes that the list is not exhaustive and that these remain hypotheses still under study.

1.2 An interpretative criterion: the rotation-deviation relationship

In the biomechanical analysis of scoliosis, observation of the relationship between rotation and vertebral deviation may provide indications regarding response to treatment.
As discussed in the previous paragraphs, physiologically the rotation of the vertebral bodies is contralateral to the lateral deviation relative to the midline axis.
In some scolioses this relationship is reversed: convexity and rotation become homolateral.
This clinical observation, derived from therapeutic practice, suggests a possible interpretative key:

Hypothesis 1: When rotation of the vertebral bodies remains opposite to the lateral deviation, physiological pattern, there may be room for improvement through treatment directed at the muscular system.

Hypothesis 2: When rotation of the vertebral bodies is homolateral to the lateral deviation, non-physiological pattern, the scoliotic curve may be so structured that it does not respond to direct work on the muscles.

This criterion represents an empirical observation that requires scientific validation and does not replace standard radiological classifications, such as Lenke or King-Moe, used in orthopaedics. It

may, however, provide additional information regarding the possibility of modifying skeletal deformities through work on the muscular system.

1.3 Application of the criterion to different phases

The proposed interpretative criterion suggests different approaches based on evaluation of the rotation-deviation relationship.

Active growth phase
Since the causes of idiopathic scoliosis are unknown, intervention during growth necessarily requires a multidisciplinary approach.
When congruence is observed between rotation and vertebral convexity, physiological pattern, there appears theoretically to be the possibility of intervening on the muscular component.
Any work aimed at reducing Resistant Force must nevertheless be assessed with the medical team.
The increase in Resistant Force observed may represent a compensatory mechanism developed by the nervous system to contain curve progression.
Interfering with this equilibrium without adequate evaluation could alter a spontaneous defensive strategy of the system.

Stabilized adult phase
After skeletal maturity, work is directed at the results of the disease, once the active phase has ended.
The approach remains multidisciplinary, but the perspectives change.
When the rotation-deviation pattern is physiological, rotation opposite to convexity, the possibility of obtaining an effective reduction in curve magnitude is greater than during the growth phase.
The system is no longer subjected to the unknown evolutionary forces of the active pathology, and work on vector rebalancing can express its potential.
The criterion therefore becomes operational: in the physiological pattern, work is directed at reducing both symptoms and curve magnitude through reduction of Resistant Force.
In the non-physiological pattern, rotation homolateral to convexity, the objective is limited to symptom control, since the deformity is likely already structured.
In both cases, the aim is to optimize the relationship between Resistant Force and Working Force in order to improve overall function.

1.4 Vector analysis in scoliosis

The analysis of the dominant vectors acting on the four muscularly independent curves is identical to that described previously.
In scoliosis, however, everything is more accentuated.
In the sagittal plane, the vertical components of the muscles acting on the two sides of the spine are vectorially different but sum together, altering the course of the vertebral sinusoid.
In the frontal plane, the horizontal components of the muscles with direct insertion on the spine may be balanced by contralateral muscles that have vectors of equal intensity but opposite direction.
The traction exerted on the thoracic vertebrae by the rhomboids, for example, may be balanced by the contralateral rhomboids, which potentially express equal and opposite force.
Paravertebral muscles contribute to counteracting lateral deviation by stiffening the spine through their longitudinal vectors.

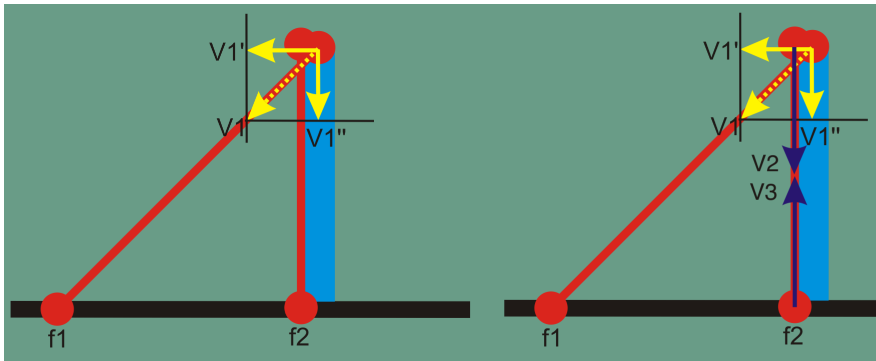


Figure 1 - Two forces, one oblique and one longitudinal, applied to a rod express different vector components. Force f1 has a vector resultant V1 composed of a horizontal component V1' and a vertical component V1". The horizontal component V1' determines lateral deviation of the rod, while the vertical component V1" stabilizes and stiffens the rod. Force f2 has vectors V2 and V3 that are purely vertical and stabilize and stiffen the rod. Expression of the horizontal component V1' may be neutralized through high-intensity work of the vertical vectors V2 and V3 expressed by force f2, to which is added the vertical component V1" expressed by force f1.

1.5 Prevalence of vertical components

All oblique muscles, in addition to horizontal components, also have vertical components. These, added to those of the paravertebrals, modify the sagittal course of the spine and stiffen it.

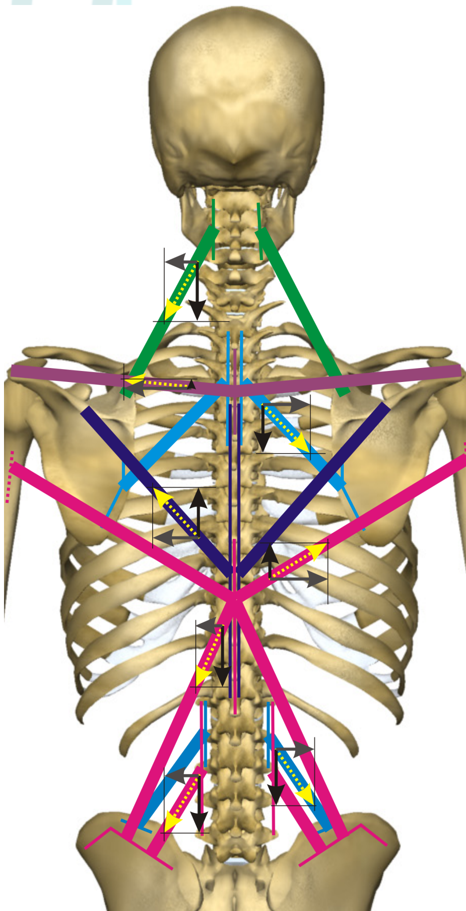
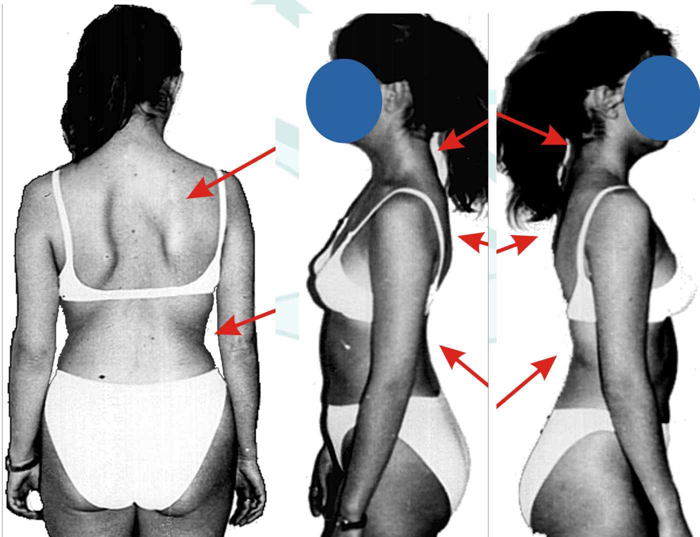


Figure 2 - Levator scapulae: green; middle trapezius fibres: violet; rhomboids: light blue; lower trapezius fibres: dark blue; latissimus dorsi: magenta; quadratus lumborum: blue. Horizontal vector components, grey arrows, and vertical components, black arrows, expressed by the oblique muscles inserting on the vertebral column. The sum of the vertical components, which alter the vertebral sinusoid and stiffen the spine, is greater than the sum of the horizontal components that laterally deviate it. If the vertical components of the oblique muscles are added to the vertical vectors expressed by the paravertebrals, the difference becomes even more marked, not shown in the figure.

1.6 Scoliosis as an expression of sagittal saturation

In the chapter on the neurophysiological model, it will be explained how the system distributes muscular shortenings in order to avoid, for as long as possible, the onset of intra-articular mechanical conflicts producing symptoms and motor impairment.
From this perspective, the appearance of lateral spinal deviations may be interpreted as the expression of saturation of the possibility of further altering the sagittal course without producing mechanical conflict.
The system, no longer able to compensate in the sagittal plane, begins to use the frontal plane.
Clinically, in the majority of scoliosis cases the spine presents as rigid and with significant sagittal alterations.



Figures 3, 4 and 5 - Twenty-four-year-old patient. Double-curve scoliosis: left lumbar convexity T12-L4, 10 degrees; right thoracic convexity T5-T12, 20 degrees. The red arrows highlight: straightening of the cervical segment as a consequence of reduction of physiological thoracic kyphosis; prominence and adduction of the scapulae with straightening of the thoracic segment; increased lumbar lordosis and anterior pelvic tilt. Alterations of the sinusoidal course of the spine in the sagittal plane are globally greater than those in the frontal plane.

1.7 Self-perpetuating mechanisms of scoliosis

Once one oblique muscle prevails over the contralateral one, laterally deviating the spine, the directions of the vector components change.
When the longitudinal vector components of the antagonist muscle project beyond the midline, they add themselves to the horizontal and vertical components of the agonist muscle.
Instead of opposing, they contribute to stabilization and worsening of the scoliosis.

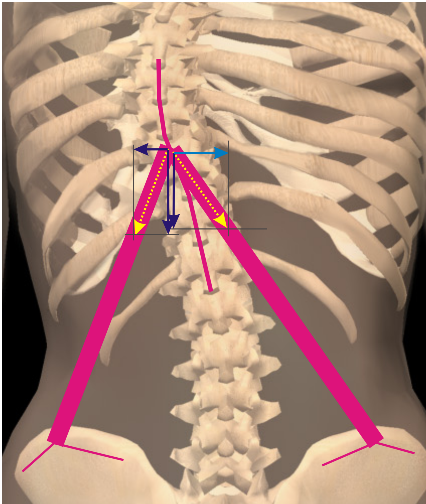


Figure 6 - Left-convex scoliosis induced by the fibres of the left latissimus dorsi extending from the iliac crest to the thoracic vertebrae T7-T12. Once the spine has deviated, the vertical vector components of the right latissimus dorsi, being beyond the midline, add to those of the left latissimus dorsi and contribute to the scoliotic deviation. The scoliosis is thus sustained by the vertical and horizontal components of the left latissimus dorsi and by the vertical vector components of the right latissimus dorsi, blue arrows. The horizontal components of the right latissimus dorsi, light blue arrow, are vectorially subdominant and cannot balance the scoliotic deviation.

The force lines of the paravertebrals also change direction once scoliosis is established. Following the deviated spine, they lose their verticality and, by adding themselves to the dominant oblique forces, contribute to fixation of the vertebral deviation.

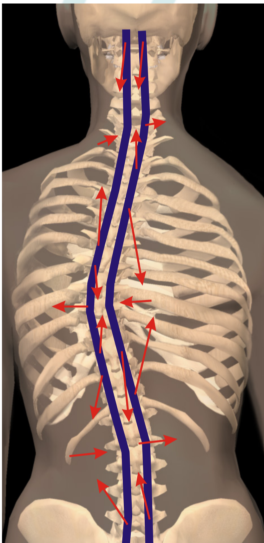


Figure 7 - Paravertebrals: blue. Scoliosis induced by muscles with vertebral insertion having oblique force lines. The force lines of the paravertebrals, following the spine, lose their vertical direction. The vector resultants of the paravertebrals, by adding themselves to those of the oblique muscles, stabilize the scoliotic curves.

1.8 Behaviour of the muscles on the side of vertebral concavity

The muscles on the concave side are lengthened relative to their initial position.
Their lengthening, however, is only apparent because it does not exceed the maximal potential lengthening of the muscle.
These muscles also increase their tension in an attempt to balance vertebral lateralization and, over time, this excess tension determines shortening of the connective tissue portion of the muscle fibre.
The muscles on the concave side are therefore in relative lengthening compared with the starting position, but globally in shortening.

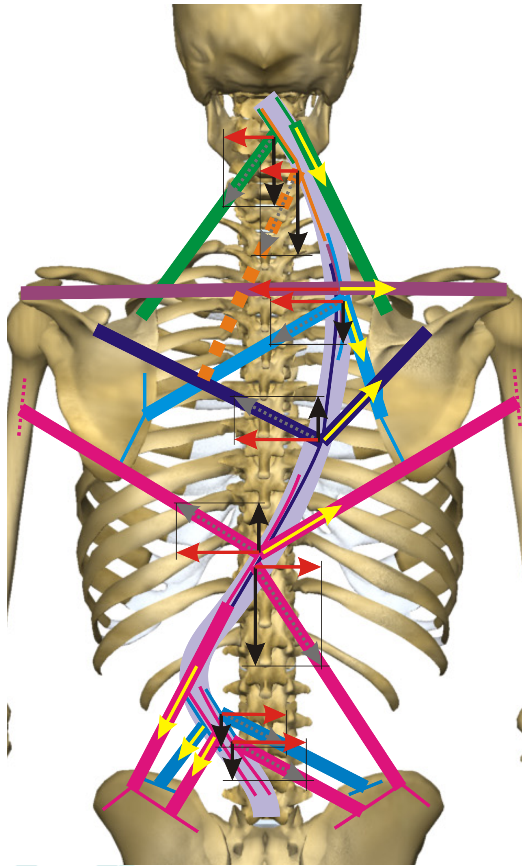
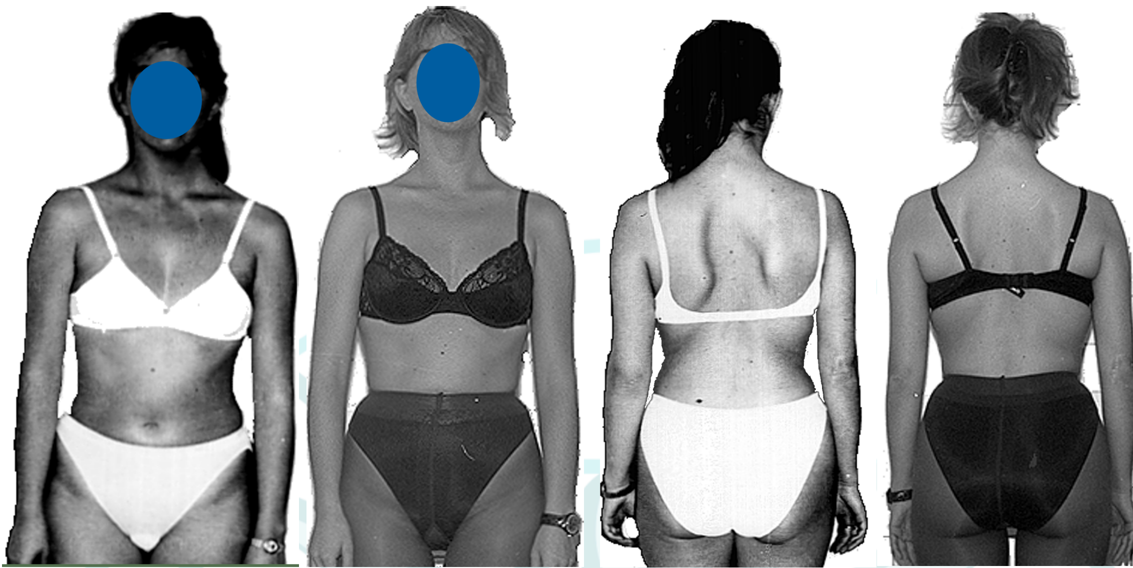


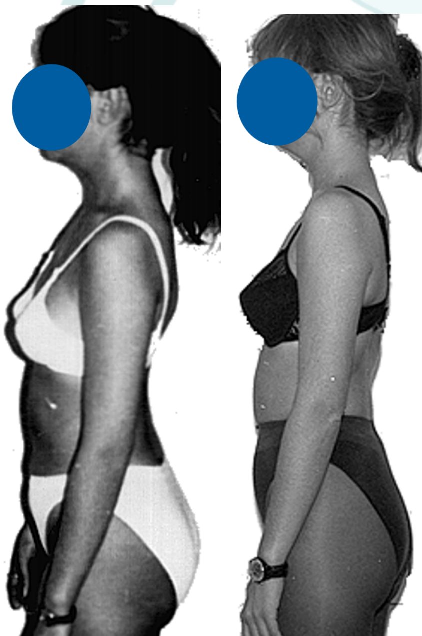
Figure 8 - Simulation of spinal course: light violet; scalenes: orange; levator scapulae: green; middle trapezius fibres: violet; rhomboids: light blue; lower trapezius fibres: dark blue; latissimus dorsi: magenta; quadratus lumborum: blue. Example of double-curve scoliosis. The muscles on the convex side pull the vertebrae laterally, yellow arrows. The muscles on the concave side increase their intensity in an attempt to balance vertebral displacement. Vector decomposition along the force lines of the concavity-side muscles shows that they have a horizontal component, red arrows, that opposes the scoliotic curve and a vertical component, black arrows, that accentuates it. Therapeutically, it is therefore necessary to reduce the excess intensity of both the muscles on the convex side and those on the concave side.

1.9 Therapeutic implications

Identification of the dominant oblique vectors determining the pattern is always necessary, but treatment cannot be directed only at these, since excess tension also affects the contralateral muscles and the paravertebrals.
It is therefore necessary to intervene therapeutically on both the muscles of the convex side and those of the concave side.
The bilateral approach is essential for interrupting the self-perpetuating mechanism described above.

1.10 Clinical example



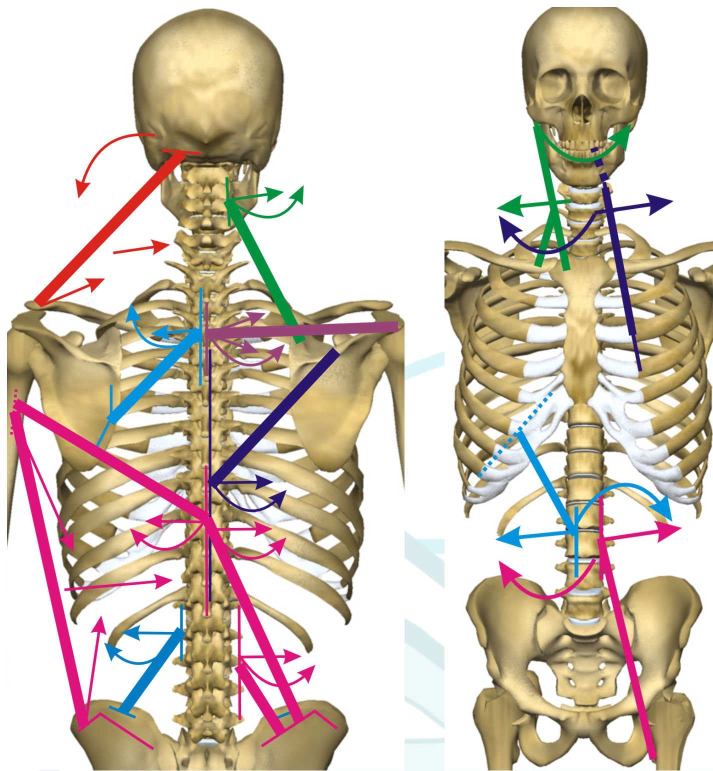


Figures 9 to 15 - Twenty-four-year-old patient. At admission, the patient presented left-convex lumbar scoliosis T12-L4 of 10 degrees and right-convex thoracic scoliosis T5-T12 of 20 degrees, entry photographs with white underwear and later photographs with dark underwear. Treatment directed toward vector rebalancing of the muscular forces acting by reducing Resistant Force in favour of Working Force produced a reduction of more than 60% in the scoliotic curves. Morphological improvements are evident in both the frontal and sagittal planes. In the sagittal plane, the apparent kyphosis is due to posterior projection of the scapula; the spine in reality presented total hypokyphosis.

1.11 Systematic classification of muscular actions

Considering the individual vector-dominant muscles, these may have a direct effect on the spine through roto-translation by virtue of their insertions, or they may produce lateral vertebral deviation as the mechanical resultant of their action on the girdles and/or on the cranium.

MUSCLE	DIRECT ACTION	INDIRECT ACTION
Upper trapezius fibres	Homolateral head inclination and shoulder elevation	Contralateral cervico-thoracic vertebral convexity
Sternocleidomastoid	Homolateral shoulder and clavicular elevation, homolateral head inclination, contralateral head rotation	Contralateral rotation of the cervical vertebral bodies
Scalenes	Contralateral rotation of the vertebral bodies C1-C7 and homolateral convexity	
Levator scapulae	Homolateral convexity of vertebrae C1-C4	
Rhomboids	Homolateral convexity of vertebrae C6-T4 and contralateral rotation of the vertebral bodies	
Middle trapezius fibres	Homolateral convexity of vertebrae C7-T3 and contralateral rotation of the vertebral bodies	
Lower trapezius fibres	Homolateral convexity of vertebrae T2-T12 and contralateral rotation of the vertebral bodies	
Latissimus dorsi, T7-T12 portion	Homolateral convexity of vertebrae T7-T12 and contralateral rotation of the vertebral bodies	
Latissimus dorsi, humerus-iliac crest portion	Homolateral hemipelvic elevation and shoulder descent	Homolateral thoracolumbar vertebral concavity
Latissimus dorsi, L1-L5 portion	Homolateral convexity of vertebrae L1-L5 and contralateral rotation of the vertebral bodies	



Figures 16 and 17 - Vertebral roto-translations induced by posterior and anterior muscles. Posterior view: upper trapezius fibres: red; levator scapulae: green; middle trapezius fibres: violet; rhomboids: light blue; lower trapezius fibres: dark blue; latissimus dorsi: magenta; quadratus lumborum: light blue. Anterior view: sternocleidomastoid: green; scalenes: blue; diaphragm: light blue; psoas: magenta.

2. Chapter summary

Transition to the three-dimensional plane requires specific methodologies. Examination in the supine position eliminates active compensations, allowing identification of true structural shortenings. Alignment of the patient on the midline, malleoli, symphysis, manubrium, and occiput, is essential for accurate assessment.
The distinction between convexity and concavity of a curve reflects different mechanisms. Convexity derives from direct muscular traction on the vertebrae and is vectorially dominant. Concavity is the mechanical resultant of displacement of other skeletal segments.
The latissimus dorsi presents two principal patterns. In pattern A, the iliac crest-humerus fascicles determine homolateral vertebral concavity through mechanical approximation of scapula and pelvis. In pattern B, the fascicles with vertebral insertion produce homolateral convexity through direct traction. Pattern B is clinically more frequent.
The spine presents four muscularly independent curves. Each segment has specific muscles responsible for deviations: cervical, levator scapulae and scalenes; cervico-thoracic, rhomboids and middle trapezius; thoracic, latissimus dorsi; lumbar, quadratus lumborum, diaphragm, and psoas.
In scoliosis, the rotation-deviation relationship has prognostic value. When rotation remains opposite to convexity, physiological pattern, there is room for improvement through muscular work. When rotation and convexity are homolateral, the deformity is structured.
Self-perpetuating mechanisms stabilize scoliosis. Once deviation is established, the vector components change direction. The contralateral muscles and the paravertebrals, instead of opposing, contribute to maintenance of the curve.
The muscles on the concave side are paradoxically shortened. Although they are in relative lengthening compared with the initial position, the excess tension in the attempt to balance the opposing forces determines shortening of the connective tissue components.

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