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Three-Dimensional Terminology of Spinal Deformity

A Report Presented to the Scoliosis Research Society by The Scoliosis Research Society Working Group on 3-D Terminology of Spinal Deformity

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Conventional terminology of three-dimensional description of spinal deformity is ambiguous and mostly tied to either a frontal or sagittal plane view of the spine. The article proposes a rationalized system for describing the shape of the spine. The spine is viewed as a line in space ('vertebral body line') with three 'angulations' specifying the orientation of each vertebra. Four axis systems are defined for the whole body, the spine, curve regions, and individual vertebrae, respectively. These in turn define the principal planes of the body, spine, curve regions, and vertebrae. Curvature can be defined as a local measure at a point on the vertebral body line, or as a regional measure between specified end vertebrae. Torsion is defined both as a local geometric property of the vertebral body line, and as measure of the relative axial plane angulations between specified vertebrae. Linear distance measures define the deviations of specified vertebrae from the local, regional, spinal, and global axis systems. Practical recommendations for positioning patients are made. This new system of terminology recognizes the 3-dimensional nature of scoliosis and other spinal deformities and is intended to rationalize communication in both research and clinical practice. [Key words: spinal deformity, terminology, standardization, three-dimensions]

Background

History

This report results from a series of informal meetings of a group of investigators whose various radiographic and analytic methods have allowed them to study spinal deformity with three-dimensional measurements. The idea of these meetings was first discussed informally at the Vancouver (1987) meeting of the Scoliosis Research Society (SRS). Meetings were then held at the annual SRS and Orthopaedic Research Society (ORS) meetings and at the combined SRS/ESDS in Amsterdam, 1989, and the ESDS in Lyon, 1992. Throughout this time the group has maintained contact with the Terminology Committee of the SRS, and has received encouragement from the SRS. The group is also affiliated with the American Society for Testing and Materials (ASTM) Committee F04.07 on standardization of testing of spinal implants and the French INSERM réseau de recherche clinique convention No. 490011.

Motivation

The study of terminology tends to be considered as a dry and thankless task, reserved for crusty and pedantic lexicologists. For us, it has proven to be anything but that. By sharing findings and insights, and by confronting the challenges of explaining exactly what we mean by our words and our research observations, we feel we have individually and collectively gained new insights and understandings of spinal deformity. The intention of this work is not to complicate the description of spinal deformity, but rather to create a framework within which we can visualize deformity more easily and communication is facilitated. We have tried to make things easier, not more difficult.

Objective

This report proposes some new terms and defines some already in use. Ideally, this terminology should be used to communicate the entire shape of a spinal deformity uniquely from one person to another. Such a system should consist, in effect, of a set of instructions by which a symmetric spine with normal sagittal curvature could be transformed into the deformed shape of the spine of a particular patient. Conversely, such a set of measurements would contain the information needed for the complete correction of the deformity.

Limitations of Two-Dimensional Measurements

There is an increasing concern about the possible etiologic, surgical, and cosmetic significance of axial rotation components of scoliosis, and of curvatures in the sagittal and other planes. Compressing the entire thorax on to the single plane of an x-ray film must handicap our ability fully to understand the deformity. Measurements of deformity and classifications of curve patterns based on the PA radiograph have not yet enabled us to predict accurately the progression or response to treatment.

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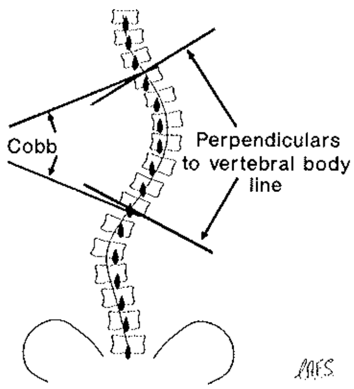

Figure 1. The Cobb method of quantifying curve severity measures both curvature and the degree of tilt of the end vertebrae. Perpendiculars to the vertebral body line measure curvature only.

Because 'curve-based' measurements are all based on the Cobb definitions of curve apex and end vertebrae, our thinking and research on spinal deformity is being constrained by measurements that are tied to the frontal plane projection of the curve. Two-dimensional measurements always simplify the real deformity of the spine. Different spinal shapes can give the same value of a particular measure. Some measures depend on more than one component of deformity (e.g., Cobb angle that measures both curvature of the spine and the projected angles of the end vertebrae, Figure 1). Three-dimensional (3D) measures provide the opportunity to overcome these problems.

What Do We Know About Spinal Deformity in 3D?

Spinal deformity involves both translational and angular asymmetry of the vertebrae, of the rib cage, and back surface. The transverse plane angulation is greatest close to the maximum lateral displacement of the spine, but the magnitudes of the transverse plane asymmetries do not correlate exactly with spinal lateral curvature magnitude, nor with each other. The vertebrae themselves become wedged and distorted so they no longer have a plane of symmetry. There are indications that the sagittal plane curvature is abnormal in patients with scoliosis, but such abnormality is difficult to quantify because kyphosis and lordosis are variable, and change with age. The abnormal lateral curvature of the spine is superimposed on the normal sagittal plane of symmetry of the spine, producing a plane of maximum curvature that is located between the frontal and sagittal plane. The vertebral rotation may differ in magnitude and direction from the rotation of the plane of maximum curvature, so, in scoliosis, the spine diverges from the plane of symmetry of the vertebrae. There are indications that skeletal proportions are abnormal, and that spinal shape and proportions are abnormal at an early stage of development of scoliosis.

The Challenge of 3D Terminology

The three-dimensional description of deformity is more realistic. Should it be brought into active use in the clinic? This step should only be taken if it can be shown that a new standard of measurement produces tangible clinical benefits. Although most of the 3D measurements have not yet been subjected to this test, we expect that their use by clinical researchers will be helpful.

Precision

The question of precision also arose often in our discussions; this relates to the problem of measurement reliability. If, for instance, vertebral axial rotation can only be measured with a reliability of ±10°, and a typical value of this rotation is 10°, then we must be cautious in using this measurement. This is the conflict between what we would like to measure and what we can measure reliably. Cobb angle too has a reliability that is close to the threshold of change (10°) at which therapeutic interventions are often considered. Precision is not only a problem of 3D measurement.

Anticipated Benefits of Using 3D Terms in Research and Clinical Practice

Much of the terminology of scoliosis is dependent on the conventions of measuring frontal plane radiographs of these patients and may have little relationship to the important parameters of the deformity. However, while not pretending to be certain that morphologic measurement will unlock all the mysteries of idiopathic scoliosis, the understanding and management of scoliosis will be helped by cautious use of the 3D tools that are available.

■ Scope

Overall Scope

This report defines terms that can be used to measure and describe morphologic aspects of spinal deformity. The terms are intended to be general and applicable to any kind of spinal deformity. Asymmetries of the rib cage, back surface, pelvis, etc. are not addressed.

Specific Problems of Scoliosis

Because of its three-dimensional nature, scoliosis deformity presents the greatest challenges. We were surprised that we could not find a good definition of scoliosis. This term is used both as an anatomic term 'lateral deviation of the spine,' and as a description of a clinical syndrome, e.g., 'idiopathic scoliosis.'

Working Definitions

These definitions are based on the geometry (shape) of the spine. "*Scoliosis* is an habitual lateral displacement of the *vertebral body line* of the spine from its normally symmetric alignment in the mid sagittal plane." Scoliosis usually involves other asymmetries of the spine and thorax in all three planes. "*Kyphosis (lordosis)* is a posterior (anterior) convex angulation of a section of the spine" (adapted from SRS 1981 terminology).

Limitations of These Proposals

The terms proposed here relate to deformity of the spine and do not include proposals for addressing the other truncal deformities (of the rib cage, pelvis, etc.) which are associated with spinal deformity. We recognized this limitation and accepted it for practical reasons.

'Quasi-3D' Measurements

Visualization of anything three-dimensional is a great challenge. The approach we adopted attempts to accommodate this human limitation by making extensive use of 'auxiliary' planes on to which the spine is projected. Measurements are then made in the auxiliary plane. Such measurements are not truly 3D, but this approach of using 'quasi-3D' measurements represents a reasonable compromise between mathematical purity and conceptual and practical limitations. The main practical limitation that results from this simplification is that the definition of a 'curve,' its apical, and inflectional vertebrae are often tied to the frontal plane projection and the Cobb definition of these features of the deformity.

Terms Not Used Here

The qualifiers hypo- and hyper- are not used here since they depend on a definition of normal range, considered beyond the scope of this work. Some terms describing spinal shape such as 'kyphosis' and 'lordosis' were not redefined here, since they are in common use and are defined in existing SRS terminology. Other terms not defined here: neutral vertebrae (with zero vertebral transverse plane angulation), inflectional vertebra (vertebra between lateral curves of opposite directions), and stable vertebra (the first vertebra caudal to a scoliosis curvature, that is transected by the global vertical (Z) axis).

■ General Principles Adopted

In describing spinal shape we used the concept of the *vertebral body line,* which is the curved line that passes through the specialized points on the vertebrae (Figure 2). It defines spinal geometry along with the orientation of vertebrae around this line. The *vertebral body line* has 3D properties expressed mathematically as length, curvature, torsion, etc.

The orientation of a vertebra is expressed by three principal angles. These are often referred to as 'rotations,' a word that is also used to describe motion as well as orientation. We chose to use the term 'angulation' to refer to a measure of the orientation of a part of the spine. 'Rotation' and 'angulation' should be considered as synonyms in reading this report.

To organize our considerations of 3-D terminology, we divided our attention as follows:

Types of Terms: Axis systems; planes; curvatures; torsions, orientation angles (of vertebrae and planes); linear distances.

Scale of Measurement: Local measures (relating to a single vertebra); regional measurements (relating to a part of the spine, usually one curve); spinal measurements (relating to the whole spine); and global measurements (relating to the whole body) (Figure 3).

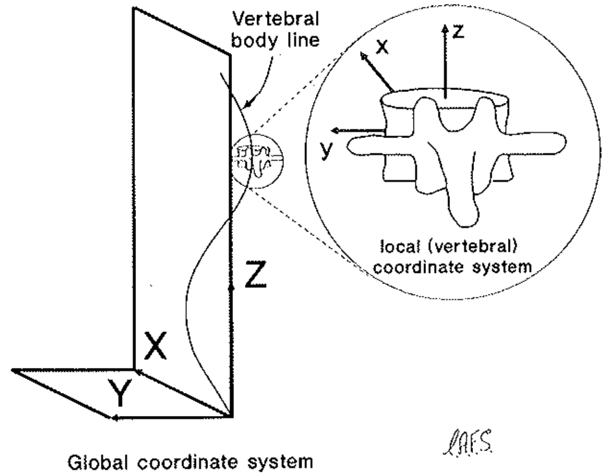

Figure 2. The vertebral body line describes the form of the spine in the global coordinate system. The vertebrae lie on this line. Each vertebra defines its own coordinate system depending on the its orientation.

This provided a logical framework for systematic examination of a wide spectrum of measurements, summarized in Table 1, with references to section of this report where terms are defined:

■ Definition of Terms

Note: Quasi-3D terms (based on projections on auxiliary planes) are identified by an asterisk.(*)

General Terms

Term: *Vertebra centroid*

Concept: The midpoint of a vertebral body

Definition: The point half way between the centers of the two endplates of a vertebra

Term: *Vertebral body line*

Concept: The curved line that passes through the vertebrae. Geometric principles, relying on vector algebra (Kreyszig, 1979;367–382) can be used to define

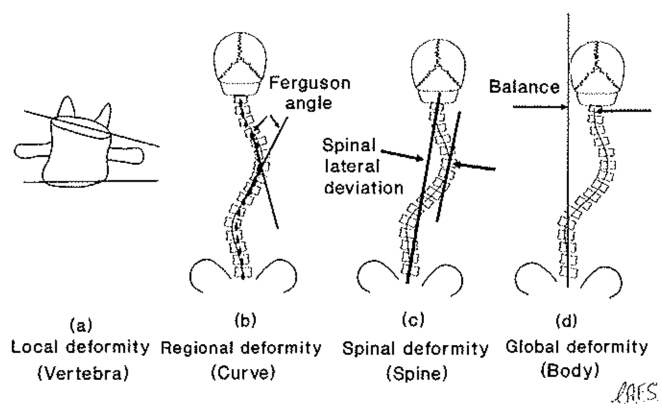

Figure 3. Examples of classes of measures of spinal deformity: a: Local measure of vertebra wedging. b: Regional measure of a curve. c: Spinal measure. d: Global measure of balance (offset).

Table 1. Guide to Sections of This Report

	Local (Vertebra or Intervertebral Joint)	Regional (Curve)	Spinal (Spine)	Global (Body)
Axis systems	1-1	(1-2)	1-3	1-4
Planes	2-1	2-2	(2-3)	2-4
Linear distances (linear position)	3-1	3-2	2-3	3-4
Orientation angles (angular position)	4-1	4-2	4-3	4-4
Curvature	5-1	5-2	5-3	5-4
Torsion	6-1	6-2	6-3	6-4

Parentheses indicate that no terms have been defined in this category.

characteristics of a line in space, and can therefore be applied to the vertebral body line (Figure 2)

Definition: The 3D curved line that passes through the centroids of the vertebral bodies.

Term: *Normal*

Concept: The line that is perpendicular to the normal plane intersecting the vertebral body line at a specified point (Figure 6)

Definition: The x axis of the Trihedron (Figure 6).

Term: (*) *Apical vertebral/disc*

Concept: The most laterally deviated vertebra or disc in a scoliosis curve.

Definition: The vertebra or disc that has the greatest y coordinate in the global coordinate system. (Revised from existing SRS (1981) terminology)

Term: (*) *End vertebra*

Concept: The cephalad and caudal vertebrae that bound a scoliosis curve, as seen in the frontal projection.

Definition: Cephalad end vertebra: The first vertebra in the cephalad direction from a curve apex whose superior surface is angled maximally toward the concavity of the curve, as measured in the PA spinal projection. Caudad end vertebra: the first vertebra in the caudad direction from a curve apex whose inferior surface is angled maximally toward the concavity of the curve, as measured in the PA spinal projection. (Adapted from existing SRS (1981) terminology)

Axis Systems

A *Cartesian axis* system is defined uniquely by an origin, and the directions of two axes. The third axis then must be perpendicular to these two. For both global and spinal axis systems of patients with scoliosis, we placed the origin at the center of the superior endplate of S1. This is a commonly accepted convention. The ISO 2631 (VDI 2057) 'right-handed' axis convention has 'x' signifying anterior, 'y' signifying left, and 'z' signifying the cephalad direction. We have complied with this principle (Figure 4).

The global and spinal axis systems should have the origin and sagittal plane defined by the pelvis, with a line parallel to the plane containing the anterior superior iliac spines (ASIS) defining the transverse global (Y) direction. (This would normally be achieved by positioning the ASIS parallel to the film plane). The other principal directions are aligned either with gravity (global system), or with spinal landmarks (see below). The apparently more logical approach of aligning the axes with the sacrum or hip joints was not accepted for practical reasons.

Exact description of an axis system is especially difficult for patients with deformity. In many cases, exact compliance with these definitions is not possible, in which case investigators are encouraged to comply with the spirit of these definitions and report their procedure.

1-1 Local Axis Systems (Local X,Y,Z).

Term: *Vertebra axis system* (Figure 5a)

Concept: A vertebra-based axis system. This axis system aligns with the plane of symmetry of an undeformed vertebra. In deformed vertebrae, it is aligned with the landmarks that define the vertebral axis system.

Definition: In this system the origin is at the centroid of the vertebral body (half way between the centers of the two endplates), the local 'z' axis passes through the centers of the upper and lower endplates, and 'y' axis is parallel to a line joining similar landmarks on the bases of the right and left pedicles.

Term: *Trihedron axis system* (Figure 6)

Concept: An axis system defined at any arbitrary point on the *vertebral body line,* as described by the Trihedron (Figure 6). The Trihedron is the basis of the formulation of Frenet's equations. This defines the rectifying plane (local plane of the line), normal plane (local tangential plane), and the osculating plane (local transverse plane)

Definition: In this system the origin is at any arbitrary point on the *vertebral body line,* the local 'z' axis is the tangent, the 'y' axis is the binormal and the 'x' axis is the *normal* of the *vertebral body line* at that point.

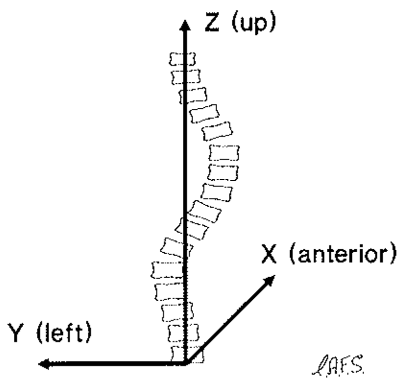

Figure 4. An axis system is uniquely defined by its origin, and the direction of two of the three mutually perpendicular axes.

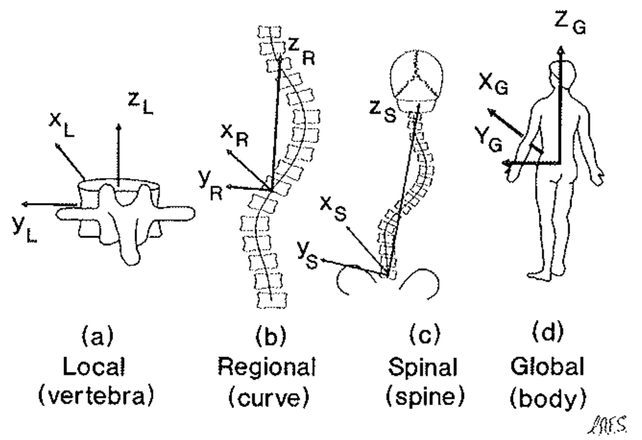

Figure 5. The hierarchy of four coordinate systems defining spinal geometry: a: Local coordinates based on a vertebra. b: Regional, curve-based coordinates defined by the end vertebrae of a curve or other spinal region. c: Spinal coordinates, defined by the Z axis passing through the centers of the most caudal and cephalad vertebrae of the entire spine. d: Global, whole body based coordinate system, with its origin at the base of the spine (S1), and the Z axis vertical (gravity line).

1-2 Regional Axis Systems (Regional X,Y,Z).

Term: None defined (Figure 5B)

Concept: A curve based axis system (e.g., 'z' axis passing through end vertebrae of a curve)

Definition: None

1-3 Spinal Axis Systems (Spinal X,Y,Z).

Term: *Spinal axis system* (Figure 5C)

Concept: An axis system for the entire spine.

Definition: This system has its origin at the center of the upper endplate of S1, the 'z' axis passes through the center of a vertebral body to be specified (usually C7 or T1), and the 'y' axis is parallel to the vertical plane containing the ASIS.

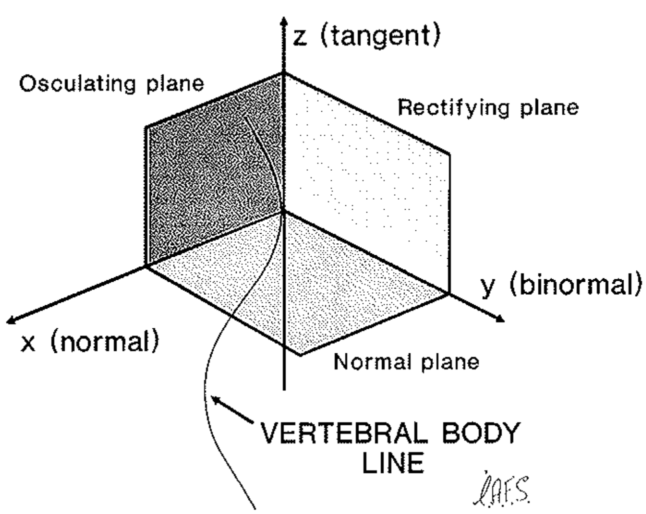

Figure 6. The Trihedron which defines a local axis system, based on the three orthogonal vectors associated with the vertebral body line. (Adapted from Kreyzig, 1979;381.)

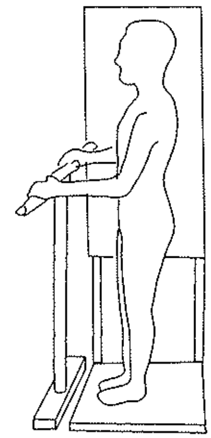

Figure 7. Patient positioning for lateral radiograph. (Adapted from Stagnara 1984;14).

1-4 Global Axis System (Global X,Y,Z).

Term: *Global axis system* (Figure 5D)

Concept: Conventional anatomic gravity-based axis system, with the origin at S1. The body is in a standing posture (for patients who stand), or as symmetrical as possible in a sitting position.

Definition: This system has its origin at the center of the upper endplate of S1, the 'Z' axis is vertical (gravity line) and the 'Y' axis parallel to the vertical plane containing the ASIS.

1-5 Recommended Procedures for Aligning Patients with Axis Systems. Patient Positioning: Measurements depend on the posture of the patient and the system of axes used. Since patient positioning depends on the unique condition of each patient and the imaging technique being used, no universal standard is possible. We recommend the standing posture (although this is not possible for some patients, and never for CT and MRI). Arm position can alter spinal shape, but arms must be positioned differently to avoid obscuring PA versus lateral views of the spine. Any attempt to equalize differences in leg length (e.g., by blocks under the feet) should be noted.

Procedure for Standing, Plane Radiographs. A global vertical or horizontal reference should be registered on each film. PA projection (for dose reasons), FFD = 2m (or 6 ft 6″), patient standing (if able to). The use of supports to position the ASIS parallel to the film plane is recommended to align the patient's global axis system with the film plane. X-ray central beam should be aimed at the 10th thoracic vertebra.

Lateral projection: Position patient as closely as possible to the same posture as was used for the PA projection. Arms can be supported in front of the patient (Figure 7). Film plane and central beam direction should be at 90° to that used for the PA projection.

Intermediate projections: e.g., plan d'élection (Stagnara 1984) as called for by specific measurement requirements.

Procedure for Sitting Plane Radiographs. Normally this must be done with anteroposterior (AP) projection. Similar precautions should be used to position the pelvis as the origin of the global axis system, and to support the arms out of the x-ray field.

Procedure for Supine Radiographs. For patients unable to stand or sit (e.g., peri-operative films) appropriate precautions should be used to maintain the pelvis as the origin of axes.

Procedure for CT or MRI. Position patient supine with arms at sides. Make a transverse section of the pelvis to provide a reference for measurements from other sections.

Procedure for Stereo (or Biplanar) Radiographs. Investigators should follow the principles described for PA and lateral projections to obtain the stereo pair of views.

Reporting. A complete description of imaging procedures includes:

- The method for positioning and supporting the patient.
- Instructions given to patient (e.g., respiration).
- The position of x-ray equipment and position of 'central beam' relative to the patient.
- The x-ray generator settings.

Planes

2-1 Local Planes

Term: Vertebral plane

Concept: The plane that is the plane of symmetry of an ideal vertebra (one not deformed by scoliosis).

Definition: The xz plane (local coordinates) of a vertebra

2-2 Regional Planes

Many of these terms are quasi 3D since they depend on the frontal plane projection of the spine for definition of a curve region.

The following are regional measures, since they measure a part of the spine (usually a curve), or are defined by a particular curve apex.

Best fit plane and *plane of maximum/minimum curvature* are similar except that 1) the latter uses a vertical plane, which is easy to obtain in an x-ray projection, whereas *best fit plane* is a general plane that may be oriented at any angle, and 2) the criteria for defining the planes are different (closest match to the positions of the vertebrae versus max/min curvature. It has been argued that use of these terms is misleading, since spinal deformity leads to a truly 3D shape of the *vertebral body line*, and even a part of it cannot be adequately represented by a 2D plane.

Term: (*) *Best fit plane* (Figure 8)

Concept: The plane that best accommodates the vertebrae in a specified region of the spine (usually a curve)

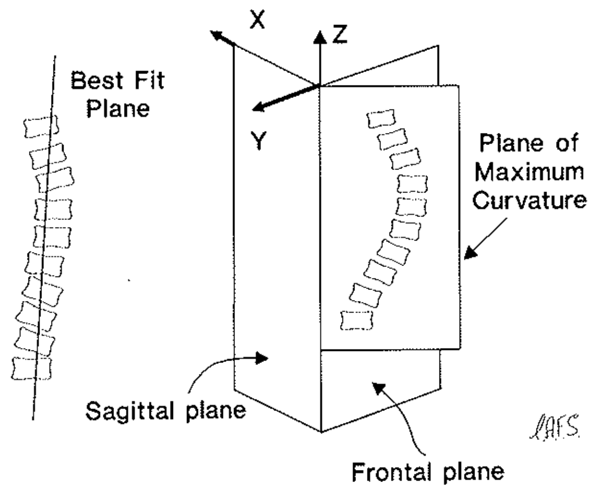

Figure 8. Best-fit plane (edge view) and Plane of maximum curvature.

Definition: The plane for which the sum of squared distances from that plane to the centroids of the vertebrae in the spinal region (curve) is a minimum

Term: (*) *Plane of maximum curvature* (Figure 8)

Concept: A part of the spine is projected on to a vertical plane which is rotated until the curvature of the projected part of the spine becomes maximum.

Definition: The vertical plane that shows the greatest spinal curvature by a specified method (e.g., Cobb) when the specified part of the spine (e.g., curve bounded by *end vertebrae*) is projected on to it

Term: (*) *Plane of minimum curvature*

Concept: A part of the spine is projected on to a vertical plane which is rotated until the curvature of the projected part of the spine becomes minimum.

Definition: The vertical plane that shows the least spinal curvature by a specified method (e.g., Cobb) when the specified part of the spine (e.g., curve bounded by *end vertebrae*) is projected on to it

Term: (*) *Apical vertebra lateral plane*

Concept: The plane which shows a lateral view of the *apical vertebra*. (A plane rotated by the transverse plane angulation of the *apical vertebra*).

Definition: The xz local plane of the apical vertebra.

Term: (*) *Apical vertebra frontal plane*

Concept: The plane which shows a frontal view of the *apical vertebra*. (A plane rotated by the transverse plane angulation of the *apical vertebra*).

Definition: The yz local plane of the *apical vertebra*.

Term: (*) *Apical vertebra plane*

Concept: A vertical plane that passes through the centroids of both S1 and the *apical vertebra* in a curve (DeSmet et al, 1984).

Definition: The vertical plane that passes through the centroid of S1 and the centroid of the *apical vertebra* of a curve.

2-3 Spinal Planes

(None defined—these would be special cases of the regional planes, where the part of the spine to which a plane is fitted is the entire spine)

2-4 Global Planes

Terms: *Sagittal plane, frontal (coronal) plane, transverse plane*

Concept: Conventional anatomic planes of the body

Definition: Sagittal plane = global XZ plane; frontal plane = global YZ plane; transverse plane = a global XY plane

■ Linear Distances and Offset (Balance)

Note: See also SRS [1976] terminology of Balance, Body alignment, Compensation, which refers specifically to Occiput alignment in the frontal plane. The 1981 revisions define only 'compensation' as the alignment (3D, dropping the frontal plane limitation) of the inion or C7.

(Im)Balance, and (De)Compensation

The word balance means different things to different people. From the point of view of the spine, it implies that, in both the frontal and sagittal planes, the head is positioned correctly over the sacrum and pelvis, in both a translational and angular sense. In the sagittal plane, the 'correct' balance is not necessarily zero, and it changes continuously as a result of postural sway (McGlashen et al, 1991). Posture is less reproducible in young children (Ashton-Miller et al, 1992). From the point of view of the trunk, balance implies that the shoulders are horizontal, and that the mass of the trunk is evenly distributed about the vertical line passing through the sacrum (the vertical global axis).

Thus "balance" implies a static alignment of a person in the standing (or unsupported seated) position. "Compensation" signifies the active process of becoming balanced, and "decompensation" signifies a failure to achieve balance, especially after an intervention such as surgery.

Offset (balance) does not exist at a local level. Usually, it is a property of the whole spine. However, at a regional level, a failure of both of the end vertebrae of a curve to lie on a global vertical axis could signify a regional lack of balance.

Spinal balance is cumulative. Unless all the translational and angular displacements of vertebrae in one direction are countered by opposite displacements and angulations of equal magnitude, the spine is unbalanced. Truncal balance is more difficult to define. In a translational sense, it involves the mass or volume of displaced segments, as well as the magnitude of their displacements. In keeping with this report defining terminology only for the spine, no attempt is made to define truncal balance (Figure 9).

Offset (balance) can be defined both as a distance and an angle. The displacement of the most cephalad vertebra from the global vertical axis (offset) can be measured as a distance from the global axis system or as an offset angle between the global and spinal axis systems.

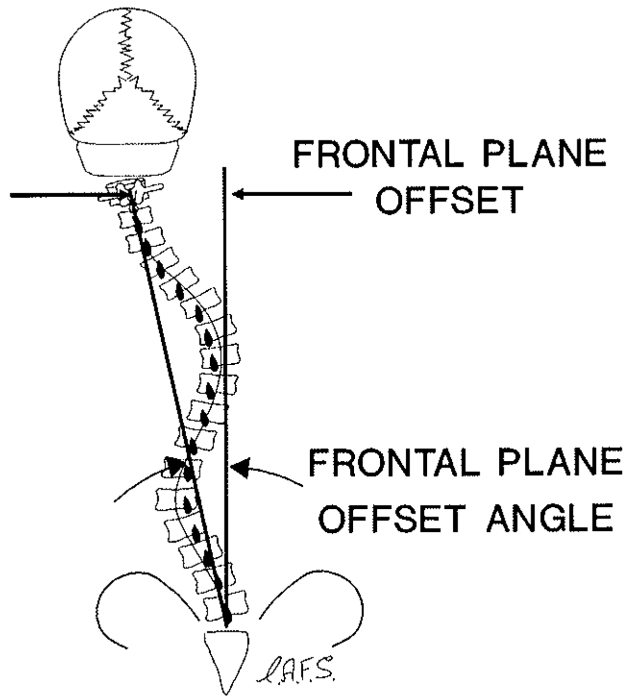

Figure 9. Balance signifies the displacement of the top of the spine relative to the sacrum (measured as a distance or offset angle) and also the degree to which the top of the spine is level (angular balance).

Angular offset is the lateral angulation of the most cephalad vertebra.

3-1 Local Distances

Term: (*) *Vertebra lateral deviation*

Concept: Where a vertebra appears in the frontal plane projection, relative to the *spinal axis system*

Definition: 'y' coordinate of the centroid of a vertebra in the *spinal axis system*

3-2 Regional Distances

Term: (*) *Regional offset (Balance)*

Concept: The relative deviations of the end vertebrae of a curve from the spinal axis.

Definition: Not defined

Terms: *Intervertebral transverse plane displacement; intervertebral frontal plane displacement; intervertebral sagittal plane displacement*

Concept: Intervertebral (between adjacent vertebrae) relative positions (and motions) are regional measurements since two vertebrae constitute the limiting case of a spinal region

Definition: The projected distances between the origins of the local axes of two adjacent vertebrae

Term: *Spinal length* (of a specified part of the spine)

Concept: 3D length of (a part of) the spine. The 3D arc length (part of) of the *vertebral body line.*

Definition: The sum of the 3D distances between centers of adjacent vertebral bodies, from the first to the last vertebra specified (e.g., occiput and sacrum or C1 to L5 for the entire spine)

Term: (*) *Curve lateral deviation*
Concept: Lateral deviation of the *apical vertebra* relative to the *end vertebrae* of the curve in the frontal plane projection.
Definition: In the frontal plane projection, the distance of the centroid of the *apical vertebra* from the line joining the centroids of the bodies of the *end vertebrae.*

Spinal Distances
Term: *Slenderness*
Concept: The ratios of transverse vertebral diameters to vertebral height and transverse vertebral diameters to overall spine length
Definition: Sagittal diameter (s) and lateral diameter (f), and spinal length (l) combined into various slenderness ratios as defined by Schultz et al, who also reported slenderness values.

Term: *Spinal lateral deviation* (Figure 3c)
Concept: Distance of the most laterally deviated vertebra from the spinal axis
Definition: The greatest spinal 'y' coordinate of the centroids of vertebrae

3-4 Global Distances and Global Offset (Balance)
Term: (*) *Frontal plane offset (= frontal plane balance)*
Concept: The distance in the frontal plane between a vertical line dropped from the most cephalad vertebra and the vertical line passing through S1 (global Z axis).
Definition: The medial-lateral (Y) distance of a defined cephalad endpoint from the global axis system (origin at S1). In practice the defined cephalad endpoints are the T1, C7 or the inion.

Term: (*) *Sagittal plane offset (= sagittal plane balance)*
Concept: The distance in the sagittal plane between a vertical line dropped from the most cephalad vertebra and the vertical line passing through S1 (global Z axis)
Definition: The anteroposterior (X) translation of a defined cephalad endpoint from the global axis system (origin at S1). In practice the defined cephalad endpoints are the T1, C7 or the inion.

Term: *Maximum lateral deviation*
Concept: Distance of the most laterally deviated vertebra from the global axis
Definition: The greatest global 'Y' coordinate of the centroids of vertebrae

■ Orientation Angles

As described in the section on general principles, spinal deformity results in altered orientation of vertebrae and of parts of the spine, which are normally referred to as 'rotations.' Since these may not actually result from a physical rotation of a previously unrotated vertebra, the term 'angulation' may be more correct and is used as a synonym of 'rotation' in this section.

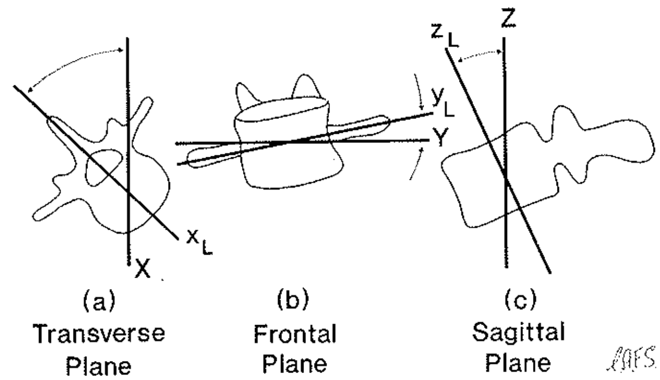

Figure 10. Three angles defining the orientation of a vertebra.

Vertebral (local) orientation angles are defined as the rotation angles that would displace a vertebra from a position in an undeformed spine to that seen in the patient with spinal deformity. The definition of such rotation angles should include the sequence in which they are made, and this becomes especially important for angles greater than 10°.

Positive directions are derived from the usual right-hand axis convention (right-hand thread rule). "Most orientation or rotation angles (especially those measured from plane radiographs) are angles projected on to a 2-D plane, and are not 3-D angles. The differences between 2-D projected angles and 3-D angles may be 20% for angles of 10°. In measuring the three angles which constitute a 3-D orientation or motion, it is important to specify their sequence" (Drerup, 1984).

4-1 Local Orientation Angles
The axes systems used in the following definitions are defined earlier.
Term: *Vertebral transverse plane angulation-vertebral axial rotation* (Figure 10a)
Concept: Amount of rotation of a vertebra about its local 'z' axis.
Definition: Angle between the local 'x' axis of the vertebra and the global 'X' axis, when projected on to the global transverse plane (+ve = counterclockwise rotation as seen from above)

Term: *Vertebral frontal plane angulation-Vertebral lateral rotation* (Figure 10b)
Concept: Amount of rotation of a vertebra about its local 'x' axis
Definition: Angle between the local 'y' axis of the vertebra and the global 'Y' axis (when projected on to the global frontal plane) (+ve = angulation to subject's right)

Term: *Vertebral sagittal (median) plane angulation = Vertebral flexion/extension rotation* (Figure 10c)

Concept: Amount of rotation of a vertebra about its local 'y' axis

Definition: Angle between the local 'z' axis of the vertebra and the global 'Z' axis, (when projected on to the global sagittal plane) (+ve = flexion)

4-2 Regional Orientation Angles

Terms: *Intervertebral transverse plane angulation (intervertebral axial rotation); intervertebral frontal plane angulation (intervertebral lateral rotation); intervertebral sagittal plane angulation (intervertebral flexion rotation)*

Concept: Intervertebral (between adjacent vertebrae) relative orientations are regional measurements since two vertebrae constitute the limiting case of a spinal region

Definition: The projected angles between the local axes of two adjacent vertebrae

Term: (*) *Apical vertebra axial rotation*

Concept: The axial rotation of the *apical vertebra* in a curve

Definition: The vertebral transverse plane angulation (*vertebral axial rotation*) of the *apical vertebra* of a curve

Term: Angle of best fit plane

Concept: The angulation from the sagittal plane of a *best fit plane*

Definition: 3-D angle between a *best fit plane* and the global XZ plane (sagittal plane)

Term: *Angle of plane of maximum curvature*

Concept: The angulation from the sagittal plane of a plane on to which a projection of a region of the spine shows the most curvature

Definition: Angle between a *plane of maximum curvature* and the global XZ plane (spinal sagittal plane)

Term: *Angle of plane of minimum curvature*

Concept: The angulation from the sagittal plane of a plane on to which a projection of a region of the spine shows the least curvature

Definition: Angle between a *plane of minimum curvature* and the global XZ plane (spinal sagittal plane)

Term: (*) *Apical angle*

Concept: Angular displacement of the apical vertebra from its normal position in the sagittal plane (DeSmet et al, 1984). This angle can be seen in a plan view of the spine projected on to the global transverse plane. It is the angle between the AP direction (X axis) and the line joining the *apical vertebra's* centroid to the origin of axes. Also it is the polar coordinate angle of the line from the origin to the *apical vertebra's* centroid in the global transverse (XY) plane.

Definition: Angle in the global XY plane between the X axis and the line joining the origin of axes to the projection of the *apical vertebra*

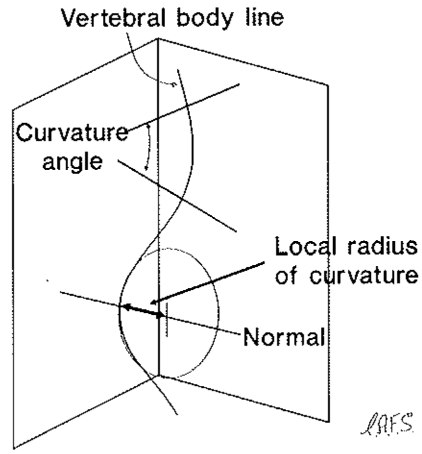

Figure 11. Curvature measurements.

4-3 Spinal Orientation Angles

None defined

4-4 Global Orientation Angles

Term: (*) *Frontal plane offset angle*

Concept: The angle between the spinal axis and the vertical (global) axis in the coronal plane

Definition: The coronal plane (YZ) angle between the line connecting a defined cephalad endpoint to S1 and the vertical gravity reference line through S1. In practice the defined cephalad endpoints are the T1, C7 or the inion

Term: (*) *Sagittal plane offset angle*

Concept: The angle between the spinal axis and the vertical (global) axis in the sagittal plane

Definition: The sagittal plane (XZ) angle between the line connecting a defined cephalad endpoint to S1 and the vertical gravity reference line through S1. In practice the defined cephalad endpoints are the T1, C7, or the inion.

Term: (*) *Frontal plane angular balance*

Concept: Balance implies that the top of the spine is positioned correctly above the pelvis, and not rotated relative to the pelvis. Angular balance measures the second of these.

Definition: The *frontal plane angulation* of the most cephalad vertebra

■ Curvature

Curvature embodies two concepts: "geometric curvature" defined mathematically as a property of the vertebral body line and measured in mm^{-1} (or conversely as a radius of curvature in mm) and "curvature angle" evaluated in degrees by various techniques: Cobb method, Ferguson method, and *analytic methods.*

Term: *Geometric curvature*

Concept: Curvature evaluated at a specified location on the *vertebral body line.* It is a vector that has both magnitude (local radius of curvature) and direction (normal) (Figures 6, 11.) Geometric curvature is calculated as the second derivative (with respect to spinal length) of the mathematical equation fitted to the *vertebral body line*. The direction of geometric curvature is the normal (the line perpendicular to both the tangent and the binormal of the *vertebral body line* at the point of evaluation).

Definition: Curvature is mathematically defined by the Frenet's formulae (Kreyszig, 1979) and evaluated at a specified location on the *vertebral body line*. It corresponds to the second derivative of the *vertebral body line* evaluated at the specified location.

Term: (*) *Curvature angle* (Figure 11)

Concept: Magnitude (in degrees) of regional (curve-based) curvature in a specified plane, measured by a specified method, which must define the end points or *end vertebrae* used. It can be evaluated by the Cobb, Ferguson, and analytic methods.

Definition: Either Cobb (Cobb, 1948), Ferguson (Ferguson, 1930) or any analytic measurement methods applied in a specified plane. Analytic methods: measurement of curvature angles using perpendiculars to the *vertebral body line* projected onto a specified plane.

Curvature Angle Measurement Methods

Although Cobb method is the widely approved method for measuring scoliosis and sagittal curvature, it really measures both curvature and vertebral body apparent tilt (Figure 1). Also, it may not be appropriate for use in other planes of projection, and in newer techniques of spinal imaging. Therefore, several methods are defined here.

Term: (*) *Cobb Method*

Concept: Angle between lines drawn on endplates of the end vertebrae

Definition: See Cobb (1948)

Term: (*) *Ferguson Method* (modified for use with defined *end vertebrae*)

Concept: The angle between lines drawn from the centroids of the *end vertebrae* to the centroid of the *apical vertebra/disc* (Figure 3b)

Definition: See Ferguson (1930) or George & Rippstein (1961)

Term: (*) *Analytic Cobb Method*

Concept: Angle between perpendiculars at inflectional points of the projection of the vertebral body line in a specified plane (Figure 1) (See Jeffries et al, Koreska et al, Stokes et al, who reported measurements of this angle, and their relationship to measurements by the *Cobb Method*)

Definition: Angle between perpendiculars to the *vertebral body line* at inflectional points in a specified planar projection.

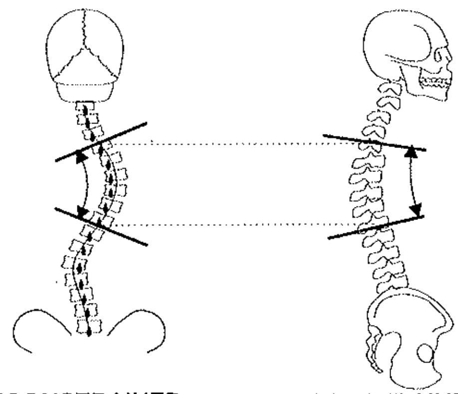

Figure 12. Curvature angle measured in a lateral plane, but with end vertebrae *constrained* to end vertebrae determined from a frontal plane.

Term: (*) *Analytic Ferguson Method*

Concept: Angle between lines formed from the inflectional point locations to the apical point computed on the projection of the *vertebral body line* in a specified plane.

Definition: For a projection of the *vertebral body line* in a specific plane; angle between lines drawn from inflectional points to the apical point.

Term: (*) *Constrained curvature angle method* (Figure 12)

Concept: To measure *constrained curvature angle*, the following are required: 1. a plane of reference, 2. defined end points for measurement of the curvature. If the end points are defined in a plane other than that in which the curvature is evaluated, this is constrained curvature (DeSmet et al). Here 'end vertebrae' may be the *end vertebrae/discs* defined for a scoliosis curve, or they may be at specified positions, e.g., specified anatomical levels. A common use of constrained curvature is to measure the lordosis in a part of the spine bounded by *end vertebrae* of a scoliosis.

Definition: Curvature angle measured in a specified plane by a specified method and in which end points for curvature measurement have been defined in a plane other than in the plane of evaluation.

5-1 Local Curvature

Term: *Local geometric curvature*

Concept: Curvature evaluated at a specified location on the *vertebral body line*.

Definition: Curvature mathematically evaluated using the Frenet's formulae at a specified point on the *vertebral body line*. (Figures 6, 11.)

Term: *Local curvature orientation*

Concept: Direction of *the normal* (Figure 11) of the *vertebral body line* relative to the global axis system.

Definition: Direction of *the normal.* It is measured relative to the global axis system by 3 projected angles.

5-2 Regional Curvature

Term: *Regional geometric curvature*

Concept: Curvature of the circular helix curve which best fits the region of the spine being evaluated (the vertebral levels have to be specified). A circular helix has a constant curvature magnitude. Therefore, this method becomes approximate for long regions of the spine, or for 'sharp' curves of changing curvature.

Definition: Curvature of the circular helix curve which best fits the region of the spine being evaluated.

Term: (*) *Curvature angle* (Figure 11)

Concept: Angle measured from projection of the spine on to a specified plane using a specified method (see section 2.0) and with defined end points or *end vertebrae.* Various curvature angles can be measured. As examples:

- Frontal Cobb Curvature Angle (scoliosis angle);
- Lateral Cobb Curvature Angle (lordosis angle, kyphosis angle);
- Frontal Analytic Cobb Curvature Angle (scoliosis angle measured as the angles between perpendiculars to the *vertebral body line* at inflectional points.
- Maximum Cobb Curvature Angle (angle measured by the Cobb method in the *plane of maximum curvature*);
- Minimum Ferguson Curvature Angle (angle measured by the Ferguson method in the *plane of minimum curvature*);
- Scoliosis Lateral Cobb Constrained *Curvature Angle* (constrained curvature angle of a scoliotic curve (frontal plane) projected into the lateral plane bounded by the frontal Cobb *end vertebrae*)

Definition: Angle measured on a specified plane with a specified method and with defined end points or end vertebrae.

5-3 Spinal Curvature

None defined

5-4 Global Curvatures

None defined

Geometric and Mechanical Torsion

Torsion has two meanings; it is a property both of the vertebral body line (geometric torsion) and of the vertebrae themselves (mechanical torsion) (Figure 11)

Mechanical torsion is the relative rotation or vertebral deformations between lines joining similar landmarks on vertebrae. It is unclear to what extent mechanical torsion results from relative motion between vertebrae, and to what extent it involves distortion of the vertebrae themselves.

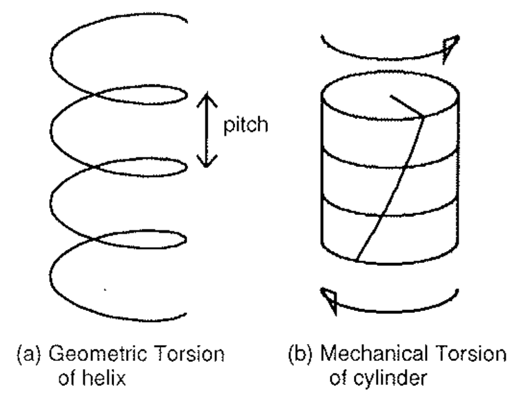

Figure 13. Concept of (a) geometric torsion (property of a line) and (b) mechanical torsion (deformation of a solid structure).

6-1 Local Geometric and Mechanical Torsion

Term: *Local geometric torsion* (Figure 13a)

Concept: Torsion or "twist" evaluated at a specific location on the smoothed vertebral body line. It is related to the amount of helicoidal deformity in the spine (and especially to the pitch of that helix). Geometric torsion measures the amount of deviation of the vertebrae (and vertebral body line) from a single plane. The torsion is zero for a circle, is zero for a straight line, and is maximum for a circular helix whose pitch is the same as the radius of its basic circle. Torsion is measured in mm^{-1} at any point on the normal of the smoothed vertebral body line. A positive value indicates a torsion in the counterclockwise direction (right handed thread rule) and a negative value indicates a torsion in the clockwise direction (left handed thread rule).

Definition: Torsion mathematically defined by the Frenet's formulae and evaluated at a specified location on the smoothed vertebral body line.

Term: *Local torsion orientation*

Concept: Orientation of the normal to the vertebral body line, relative to the global axis system.

Definition: Orientation of the normal to the vertebral body line, measured relative to the global axis system by three projected angles.

Term: *Local mechanical torsion* (Figure 13b.)

Concept: Vertebral deformation due to the torsional deformity of the scoliotic spine. Up to now, no one has defined or used local mechanical torsion.

Definition: Vertebral deformation due to the relative axial rotation (angulation) of the endplates.

6-2 Regional Geometric and Mechanical Torsion

Term: *Regional geometric torsion*

Concept: Torsion of the circular helix curve best fitted to the region of the spine being evaluated (the vertebral levels have to be specified). A circular helix has a constant torsion.

Definition: Torsion of the circular helix curve best fitted to the region of the spine being evaluated.

Term: *Regional mechanical torsion*

Concept: Difference in vertebral axial rotation (including vertebral deformations and rotations) between two specified vertebrae. One example is Perdriolle's measurement technique with the "torsiomètre" which can be used to measure regional mechanical torsion between the neutral vertebra (vertebra with no axial rotation as seen in the frontal plane) and the apical vertebra of a scoliotic section of the spine.

Definition: Difference in vertebral axial rotation (including vertebral deformations and rotations) between two specified vertebrae and the end vertebrae of a curve.

6-3 Spinal Geometric and Mechanical Torsion

Not defined

6-4 Global Torsion

Not defined

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