THE VALIDITY AND RELIABILITY OF MEASUREMENTS IN SPINAL DEFORMITIES : A CRITICAL APPRAISAL

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Quantitative measurement of spinal deformity is the preliminary step in order to plan a therapeutic regimen. The most commonly used methods and, for this matter, practically any measurement methods, may have several sources of errors, namely :

a. errors in taking a radiograph ;
b. errors intrinsic to the measurement method ;
c. errors due to anatomical deformity of the vertebrae ;
d. observer errors in measurement technique.

These are discussed, and suggestions are given to minimize them.

Keywords : measurements ; Cobb method ; Ferguson method ; radiographs ; vertebral deformity.
Mots-clés : mesures ; méthode de Cobb ; méthode de Ferguson ; radiographie ; déformation vertébrale.

INTRODUCTION

The vertebral column is embedded between the paravertebral muscle masses. In a lean person, it is possible to roughly assess its shape by inspection and palpation, but to study spinal deformity in detail it is necessary to use imaging techniques. Radiographs are the simplest, cheapest and most reliable means to assess the initial deformity, and to follow-up and evaluate the effects of treatment on spinal deformities (27). It is therefore important to know the accuracy of the method of measurement used (40). Several methods have been described to measure more objectively some parameters such as vertebral rotation (7, 34, 38) and skeletal maturity (44).

Clinical examination is therefore important, but radiographic evaluation is essential to quantify the deformity (47), although this may give only limited information. Most studies have focused on the magnitude of the curve as the fundamental parameter of spinal deformities (11, 12, 36). Radiography is a simple, cheap and fast way of quantifying a curve. For this reason, the measurements chosen should be performed in the best possible way (29) in terms of both reliability and validity, especially in spinal deformities with a poor prognosis (27).

Idiopathic scoliosis is a spinal deformity in 4 dimensions (12). In this respect, the determination of an increase in magnitude of a curve is an important, and difficult, task to accomplish. As a radiograph displays a tri-dimensional structure in 2 dimensions (9, 22, 28, 31), the conventional anteroposterior and lateral views depict the deformity obliquely because of vertebral rotation (15).

Angular measurements define only partially a spinal curve, and other parameters must be considered, such as :

1. vertebral deformity (7, 32) ;
2. thoracic deformity (1, 33) ;

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3. the general appearance of the curve (1, 24, 41) ;
4. skeletal maturity (4, 44) ;
5. reducibility (41, 16) ;
6. rotation (1, 34, 38).

Vertebral rotation is probably the best known of the above (1, 34, 38). To quantify it, Cobb measures the distance that the apical spinous process was displaced towards the concavity of the curve (7). A similar method was described using the pedicles (38). Subsequently, the morphological characteristics of a spine x-rayed at different degrees of rotation have been studied (34). The latter method gives only approximate values, but is able to monitor rotation through 90°.

The purpose of this article is to discuss the commonest causes of error in routine angular radiographical measurements of a spinal curvature, and to identify some possible solutions to them. It focuses on idiopathic scoliosis and on angle measurement, mainly from a geometrical viewpoint, but the considerations may be applied to most spinal deformities. It should be stressed that the clinician needs to consider the shape of a given spinal deformity as well as the numerical value of that deformity.

ANALYSIS OF THE DIFFERENT CAUSES OF ERRORS

On theoretical grounds, the causes of error in angle measurement can be grouped as follows :

A. errors in taking a radiograph ;
B. errors intrinsic to the measurement method ;
C. errors due to anatomical deformity of the vertebrae ;
D. observer errors in measurement technique.

Group A : Errors in Taking a Radiograph

There are two possible errors :

1. *Intrinsic projection errors.* A scoliotic curve does not lie in a lateral plane, but rather forms a helix (14). An anteroposterior (AP) or a postero-anterior (PA) view does not then show real curves. This is why it hs been suggested that a radiograph be taken in the "election plane" (15, 48).

2. *Errors due to patient and/or tube positioning.* Several authors (8, 12, 36, 42) have focused on appropriate patient positioning while standing, with consideration of flexion deformity of hips and knees, rotation of hip and shoulder joints and lower limb length inequality. An inaccurately centered x-ray tube causes small changes shown on the film as variation in the magnitude of the curve.

These changes may vary between − 11° and + 9° using the Cobb method, and between − 5° and + 3° using the Ferguson method (48). If all other parameters remain the same, these changes may be affected by vertebral rotational alterations (34). Although the importance of rotational evaluation of a curve has been repeatedly stressed (7, 34, 38), this is often not taken routinely into account in the assessment of deformities, probably for several reasons. For example, vertebral rotation is not easy to evaluate even in a normal spine (38). The task is more daunting in a curved spine because of the anatomical alteration occurring in the vertebrae due to the deforming forces (9, 35). The shape of a scoliotic vertebra is often of an irregular trapezoid, not of a perfect rectangle as is classically described.

Small positional changes of the patient may result in significant errors in curve evaluation (5, 8). A standard AP free-standing view may show a difference of up to 17° when compared with a radiograph taken with special devices (8). These imprecisions can be significant in curves with a Cobb angle of less than 20°, where the need for precision is higher and it is important to assess small angular variations to detect the progression of a curve (40).

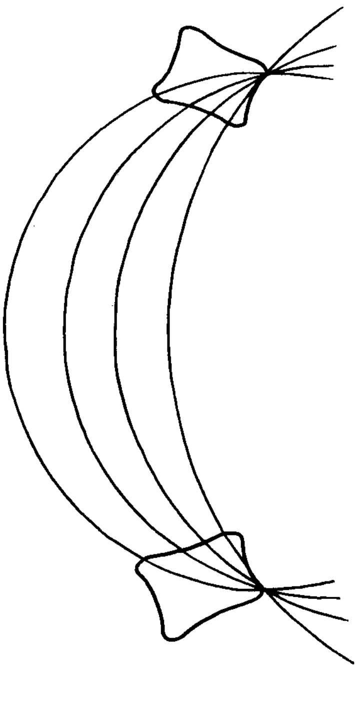
In this category, an additional source of errors may be the psychological attitude of the subject. It is easily understood how spatial positioning is influenced by the subject's psychological status, which may change with time. To the best of our knowledge, the differences in spinal measurements due to the above problem have never been studied and quantified. To avoid this inconvenience, standard positioning should be used.

Group B : Errors Intrinsic to the Measurement Method

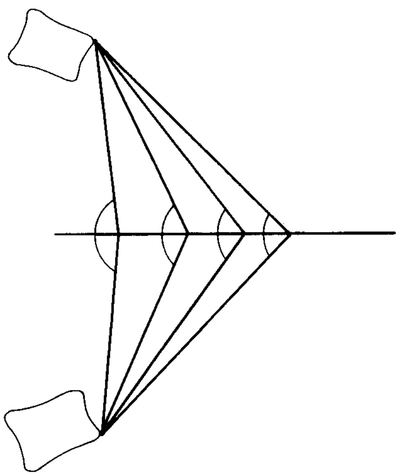
Most of the present measurement methods are performed as if a curve were lying just in one plane (18, 29). In this case, they all show the same basic error, both on AP and PA radiographs (13). The only advantage of the latter is that it allows a reduction in exposure to radiation (2, 37, 46). Each method shows some intrinsic geometric imprecisions (39).

1. *The Cobb method* breaks down the deformity into a number of curves, thus isolating the different vertebral segments according to the radius of curvature of the concavity of the curve. The curve resulting from the composition of the smaller curves is then measured. The radius of curvature of each vertebra varies according to the spinal segment considered and the deformity of the vertebrae (9).

The Cobb method identifies an angle drawing lines parallel to the superior and inferior surface of the cranial and caudal neutral vertebral bodies of a scoliotic curve. However, 3 points are needed to define a curve, as an infinite number of curves with their relative angles at the center may pass through 2 points only (6, 39, 49) (diagrams 1 and 2, and figs. 1 to 3). The measurement of the Cobb angle itself then lacks precision. A variation of ± 5° to 7° is to be expected, particularly when measurements are carried out by different operators (5, 30).



Diagr. 1



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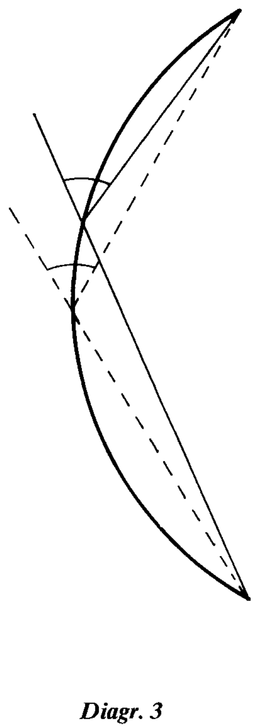


Diagr. 3

Diagr. 1 and 2. — Geometric error intrinsic to the Cobb method. An infinite number of curves may pass through 2 points (diagram 1), and an infinite number of angles at the circumference may thus be defined (diagram 2).
Diagr. 3. — Error intrinsic to the Ferguson method. The absolute distance between 2 points of the spine may be the same, but, as the vertebral body height increases progressively from C2 to L5, the angle at the circumference may vary depending on the segment the curve is on.

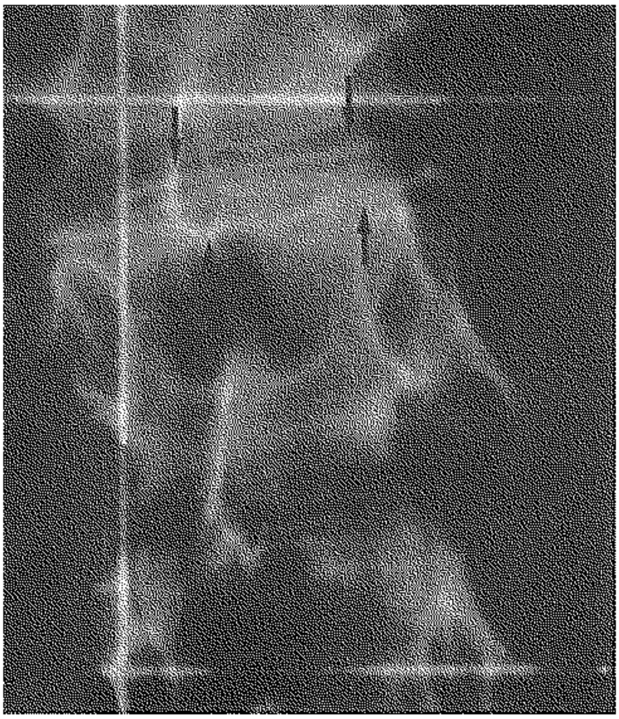


Fig. 1a

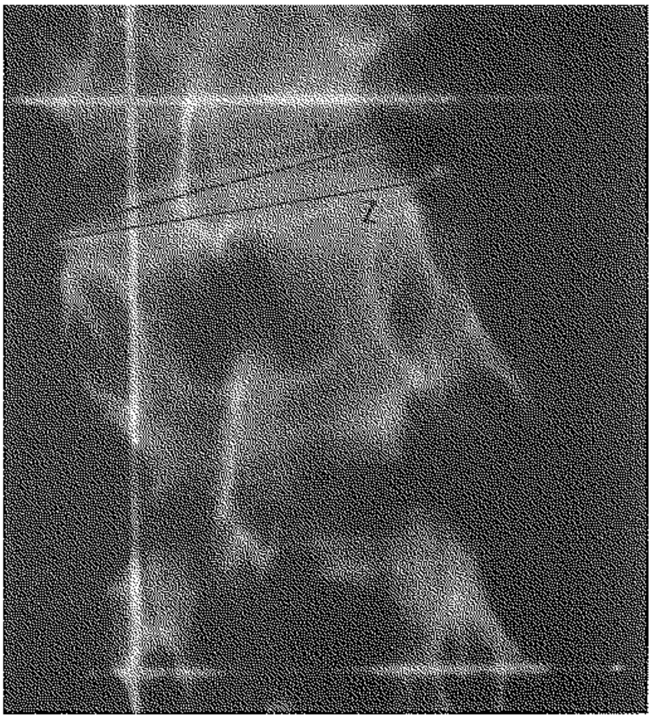


Fig. 1b

Fig. 1. — 1a: The Cobb method should identify the angle at the center because the tangents to the superior surface of the top vertebra and to the inferior surface of the lowest one are perpendicular to the tangents of a scoliotic curve. However, this figure shows how the surface of the upper limiting vertebra of a scoliotic curve appears to be oval. It is therefore possible to draw a nearly infinite number of tangents to it, 2 of which are drawn in fig. 1b. With the Cobb method, for each tangent drawn a different angle is obtained for the same curve.

When the Cobb method is used for follow-up purposes, an apparent improvement may be achieved (18) as the standard anteroposterior view underestimates the true extent of a spinal deformity (14). This is more marked with increasing curvature. As the curve rotates past the coronal plane, it is progressively directed more posteriorly (14). Thus, an AP view will show a decreasing Cobb angle when the opposite is happening to the curve, because such a projection is only anteroposterior to the vertebrae above and below the curve, not to those that are part of the structural curve (14, 25).

An intra-observer variability of 2.2° to 3° on the same radiograph is to be expected (3, 23). The error is increased to about 6° when different observers are allowed to choose independently the limiting vertebrae (14). This imprecision is reduced using the "scoliotic index" method (19), which has the disadvantage of being complex, and requiring a computer.

2. *The Ferguson method* (17) identifies in a geometrically sound way (i.e. using 3 points) a curve formed by the vertebral body centers. In order to determine the Ferguson angle, after having identified the centers of the upper and lower vertebrae of the curve, and of the apical vertebra, 2 lines joining the center of the apical vertebra with the upper limiting vertebra, first, and the lower limiting vertebra, successively, are drawn. The intersection of these lines identifies the Ferguson angle. It defines an angle to the circumference, not an angle at the center. For such an angle to be defined properly, it is necessary that the distances between the centers of the limiting vertebrae and the center of the apex vertebra are

equal (29) (diagram 3). The vertebral body height increases progressively from C2 to L5 (diagram 3), and so the angle to the circumference is not exactly half of the angle at the center (29). Because of the growth process, a different angle to the center (and an angle different from the previous one) is measured each time, resulting in 2 errors in the comparison. The inequality between the distances between the centers may vary with growth (49). Even if the distances were the same, the measurement of the Ferguson angle would still be less sensitive by 50% relative to the measurement of the angle at the center. Obviously, any variations would be more difficult to show (39).

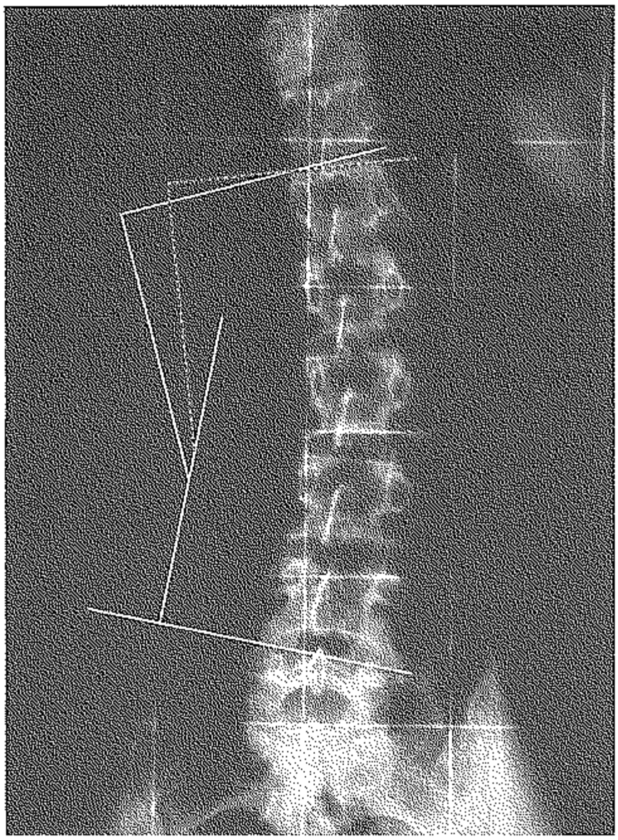


Fig. 2. - The same scoliosis shown in fig. 1. A practical application of the principles discussed in fig. 1. Just by changing the tangent to the upper limiting vertebra, we obtain a difference of 9°. (The curve would measure 17° using the interrupted line, and 26° using the continuous line.)

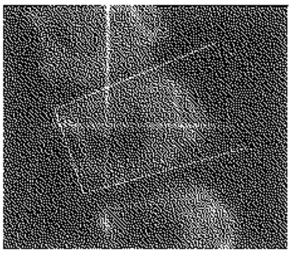


Fig. 3

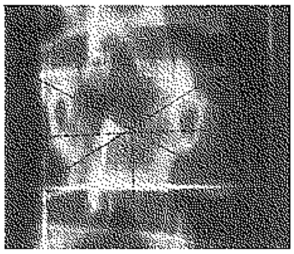


Fig. 4

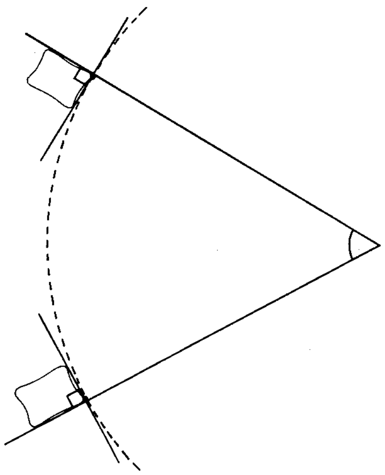
Fig. 3. — In a curved spine, anatomical alterations occur in the vertebrae due to deforming forces. The shape of a scoliotic vertebra is often an irregular trapezoid, not a perfect rectangle as commonly described. The line A, tangent to the upper surface of the upper limiting vertebra of a curve, is not perpendicular to B. Therefore, it will not intersect the center of the circumference of the scoliotic curve. The same problem may be encountered when the tangent to the lower surface of the lower limiting vertebra is drawn.

Fig. 4. — When wedging is present, to identify the center of a vertebra it is necessary to draw the lines perpendicular to the middle points of each side of the vertebra. The intersection resulting from these lines is the geometrical center of the vertebra, even though the vertebra itself is deformed. Using only diagonals may result in the identification of a spurious center.

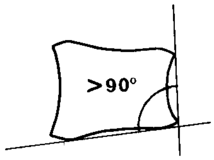
Group C :
Errors due to Anatomical Deformity of the Vertebrae

The methods used to measure spinal deformities are based on geometry, and they are therefore sensitive to deformity of the vertebral body.

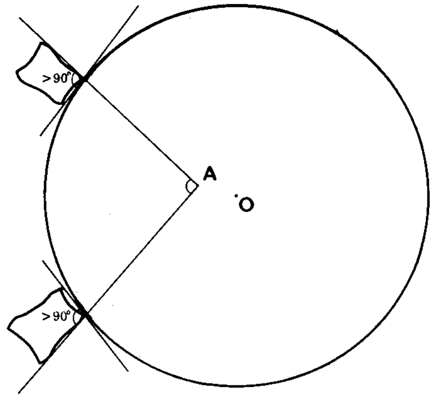
1. The *Cobb method* should identify the angle at the center because the tangents to the superior surface of the top vertebra and to the inferior surface of the lowest one are perpendicular to the tangents of a scoliotic curve (diagram 4). Due to deforming forces, significant wedging of the vertebral bodies may be present (14). Thus, the tangents to the vertebral bodies are not perpendicular to each other and their angular relationships are altered (diagram 5). In this case, the angle constructed is no longer the hypothesized angle at the center, as point A does not coincide with point O (diagram 5). The difference between the real angle at the center and the Cobb angle is increasingly greater with increasing vertebral deformity (6) (diagram 6).



Diagr. 4



Diagr. 5



Diagr. 6

Diagr. 4, 5 and 6. — The Cobb method is based on drawing tangents to the vertebral bodies. This is geometrically feasible if the vertebral bodies are of normal shape (diagram 4), but wedging may occur (diagram 5), thus resulting in a significant error (diagram 6).

2. The angle identified by the *Ferguson method* is half the angle to the center (29), but it is often extremely difficult to identify the center of the apical vertebra because it is the most deformed one (45) (fig. 4). Consequently, the relationship with the angle to the center is more discordant (27).

Group D : Observer Errors in Measurement Technique

The possible error introduced by measurement can be classified as :

1. *identification errors* :

i. errors in identifying the top and bottom vertebrae of the curve (23, 32) ;
ii. errors in identifying the apex vertebra of the curve (27) ;

2. *technical errors* :

i. errors in drawing the tangents of the vertebral bodies using the Cobb method, as it is not possible to draw lines exactly tangent to elliptical surfaces (27). This may induce a measurement error of up to 10° (18, 43, 45) ;
ii. errors in identifying the center of a vertebral body using the Ferguson method, especially when, due to wedging, the two diagonals do not meet exactly at the center (27) ;
iii. errors due to inappropriate choice of the writing instrument. A thinner instrument is more accurate (40).

The most frequent and significant error is the choice of the vertebrae (40). Once the correct vertebrae have been chosen, intratester reliability is close to 95% (4).

DISCUSSION

The main purpose of this paper is to identify, define and discuss the possible remedies to the above-mentioned intrinsic geometric errors.

Group A : Errors in Taking a Radiograph. Due to the intrinsic projection error and to vertebral rotation, radiographs should be taken in the election plane (15, 48), unless the otherwise difficult to quantify error is considered acceptable. In this case, only AP or PA views are taken. Due to the effect of progressive vertebral rotation, it can be difficult, time-consuming, expensive and potentially dangerous to identify the election plane in longitudinal studies.

Positioning errors of patients and/or the tube can be circumvented with accurate supervision. For this purpose, devices such as the 'scoliosis chariot' (8) have been employed. They favor perfect standard positioning of both the tube and the patient. As an alternative to monitoring the patient position, errors may be reduced taking sequential radiographs (5). To try and avoid the inaccuracy of bidimensional measurements on radiographs, a tridimensional computerized reconstruction has been proposed (10, 20, 21, 22, 31), and previously described methods have been modified (26).

To accurately measure a curve using the Cobb method, the tangents to the vertebral bodies must be exactly parallel to the direction of the x-rays (48). As this is not possible owing to kyphosis and lordosis, a hypothetical projection called 'rectified orthogonal projection' has been proposed (31). With a computer, this projection correctly represents all angles in accordance with these principles (31).

The real usefulness of computerized techniques in routine clinical practice has not yet been verified (22), and the practical applicability must be improved. These techniques may be of interest for research and clinical purposes if the aforementioned points are addressed. Uniform positioning and technique are important but not critical to ensure reliability of serial curve measurements (47).

Group B : Errors Intrinsic to the Measurement Method. Intrinsic errors cannot be avoided. As it is not possible to show a geometrical correlation between the Cobb and the Ferguson methods (18, 39, 47), it is necessary to measure accurately the real angle to the center. This should allow a precise definition of the curve and of the angle subtended by it (6) (fig. 5 and 6).

Group C : Errors due to Anatomical Deformity of the Vertebrae. The errors implied by the common measurement methods are unavoidable in this group as well. At least theoretically, a method which is not influenced by vertebral deformity and rotation should be used (6). Some computer-based methods in which this source of error is considered have been described, but they have not yet been subjected to routine clinical use due to their difficulty and cost (10, 23).

Group D : Measurer's Errors. To identify the extremes of a curve, it is necessary to evaluate the inclination of the vertebral bodies. The limiting vertebrae are the most oblique ones (23), while the apical vertebra is the most rotated and wedged one (7, 34, 38). Using the Cobb method, if the limiting vertebrae are not clearly evident, the cortical margins of the pedicles can be of help (27), and it is often easier to allow for the vertebral spaces when drawing the lines (27). With the Ferguson method, if wedging is present, it is necessary to draw the lines perpendicular to the middle points of each side of the vertebra. The crossing resulting from these lines is the geometrical center of the vertebra, even though the vertebra itself is deformed (27).

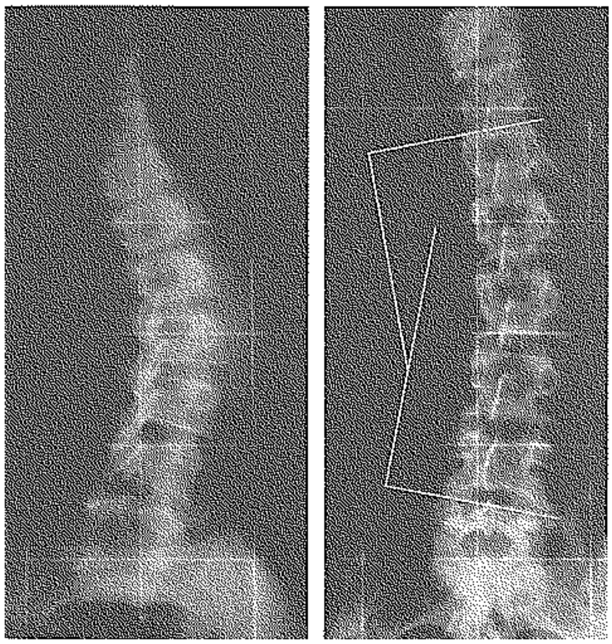


Fig. 5a *Fig. 5b*

Fig. 5. Dorsolumbar scoliosis at the beginning of the treatment (fig. 5a) and after 3 years (fig. 5b). Based on three different mlethods, the angular value has decreased from 28° to 20° (29%) (Cobb), from 23° to 15° (35%) (Ferguson), and from 72° to 40° (45%) (Capasso). The angular values obtained are very different due to the sensitivity and precision of each of the methods.

CONCLUSION

The above-mentioned concepts can be used in clinical practice in evaluating curves of around 20° and around 50°, i.e. when the decision must be made between noninterventional, bracing or surgical programs (40, 50). Once the possible causes of error have been identified, and the reliability of measurements assessed, it should be easier to decide on a management program, and to evaluate the results (fig. 7).

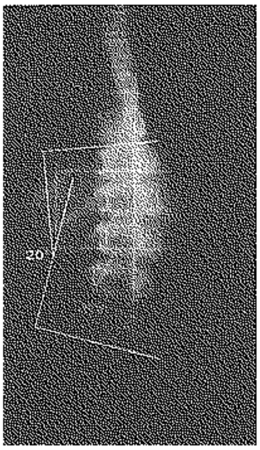


Fig. 6

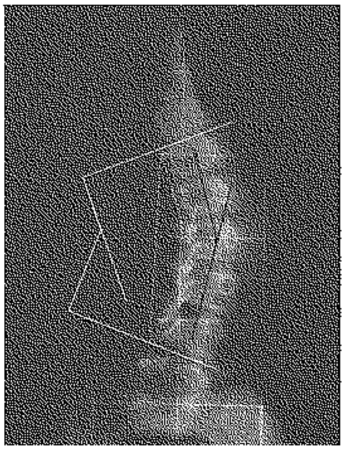


Fig. 7

Fig. 6. — Dorsolumbar scoliosis extending over 5 vertebrae. By the Cobb method, it measures 20°, the same value as the curve shown in fig. 5b. Beyond the considerations of vertebral rotation, the entity of the curve is different. If the shape of the two curves is compared, the scoliosis of fig. 6 is more accentuated, despite both having the same Cobb angle of 20°. Using the Ferguson method, the curve in fig. 6 measures 17°, i.e. 2° (13%) more than the one shown in fig. 5b. With the Capasso method, the curve in fig. 6 measures 48°, i.e. 8° (20%) more than the one shown in fig. 5b.
Fig. 7. — Food for thought : three of many methods in comparison (Cobb : white line ; Ferguson : black line ; Capasso : interrupted line). Which is the most sensitive method in evaluating small variations of the curve ? Which is the easiest to use ? Which shows the least inter- and intratester variability ?

Acknowledgements

Many thanks are given to Mr. P. J. Webb, FRCS, Consultant Orthopaedic Surgeon, Royal National Orthopaedic Hospital, Stanmore, Middlesex, England, for helpful discussion, suggestions and critical reading of the manuscript. We are deeply indebted to Mrs. J. Baines-Preece for reviewing the manuscript.

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SAMENVATTING

G. CAPASSO, N. MAFFULLI, V. TESTA. Waarde en betrouwbaarheid van de metingen bij wervelkolommisvormingen. Kritische studie.

De kwantitatieve meting van een wervelkolommisvorming is de eerste onontbeerlijke stap bij het bepalen van een therapeutisch plan. De meest gebruikte technieken en, voor deze specifieke materie, praktisch al de meettechnieken, zijn behept met mogelijke fouten, met name :

a. fouten bij het rö-onderzoek
b. fouten eigen aan de meettechniek
c. fouten gebonden aan de anatomische misvorming van de wervels
d. menselijke faktoren bij de evaluatie.

Al deze gegevens worden ontleed en er worden suggesties gedaan om ze tot minimum te herrleiden.

RÉSUMÉ

G. CAPASSO, N. MAFFULLI, V. TESTA. Valeur et fiabilité de la mesure des déformations vertébrales. Étude critique.

La mesure quantitative d'une déformation vertébrale est un préalable indispensable à l'établissement d'une thérapeutique. Les méthodes les plus courantes et, dans le domaine traité, pratiquement toutes les mesures, peuvent présenter des sources d'erreurs, notamment :

a. erreurs lors de la prise du cliché
b. erreurs inhérentes à la technique de mesure
c. erreurs dues à la déformation anatomique des vertèbres
d. erreurs humaines dans l'évaluation.

Ces éléments sont discutés et quelques ssuggestions en vue d'en réduire l'importance, sont présentées.