Moiré Fringe Topography and Spinal Deformity

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Determination of degree of correction of spinal deformity by moiré topographs

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Abstract

Degree of correction of spinal deformity is defined in terms of three dimensional angles of spinal curvature in the normal and hanging positions.

1. Introduction

The spinal curve measured by Cobb's or Risser-Ferguson's method (Turek, 1967; Tachdjian, 1962) from posterio-anterior roentgenogram gives information about scoliosis. Three dimensional angle of spinal curvature, named as 'Asr Angle' is defined in terms of direction cosines of spine (Kamal, 1982). 'Asr' (Arabic) means frame, and is taken from the following verse of Al-Quran

نَحْنُ خَلَقْنٰهُمْ وَشَدَدْنَآ أَسْرَهُمْ ۚ وَإِذَا شِئْنَا بَدَّلْنَآ
أَمْثَالَهُمْ تَبْدِيلًا ﴿٢٨﴾

"We, even We created them, and strengthened their frame. And when We will, We can replace them, bringing others like them in their steed" (Sura 76:28).

This paper describes a method to calculate 'Asr Angle' in the normal and hanging positions as well as degree of correction of spinal deformity from moiré topographs of back and side.

2. Measurement of the Angle of Spinal Curvature in Two Dimensions

A relation for the measurement of two dimensional angle from moiré topograph of back is derived elsewhere (Kamal, 1980) and applied in different clinical situa-

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tions (Kamal and Lindseth, 1980; El-Sayyad and Kamal, 1981). Here the method is briefly described. The angle of spinal curvature for the case of a single curve scoliosis can be written as (Fig. 1)

$$\Theta = \angle CAO + \angle CBO = \gamma_1 + \gamma_2 \qquad (1)$$

To measure this angle, the midpoint of neck P is joined to the midpoint of waist Q. From the line PQ, the distance to the first visible moire fringe on both sides is measured at different points. The position of spine is obtained by taking the average of these distances. From the position of spine at a given point, the distance to the line PQ is obtained as d. If we are able to find a point on line PQ on both sides of which the moiré fringes have maximum asymmetry, the distance at this point will be maximum and is denoted by d_1. Let E and H be the points on the nearest visible moiré fringe corresponding to right and left sides of the back such that line HCE is perpendicular to line PQ. The point O is the midpoint of the line segment HE. If we consider C as origin and take the distance on the right as positive and that on the left as negative we have

$$d_1 = \tfrac{1}{2}(CH + CE) \qquad (2)$$

At point A above the point C on line PQ, where the moire fringes show minimum asymmetry d should be minimum and is given by

$$d_2 = \tfrac{1}{2}(AD + AG) \qquad (3)$$

At point B below the point C on line PQ, where the moire fringes show minimum asymmetry, the distance is given by

$$d_3 = \tfrac{1}{2}(BF + BI) \qquad (4)$$

Therefore

$$\tan \gamma_1 = |d_1 - d_2|/CA, \quad \tan \gamma_2 = |d_1 - d_3|/BC \qquad (5)$$

The railroad sign line in Fig. 1 represents the position of spine. Another way (El-Sayyad and Kamal, 1981) is to take measurements at two points below the point of maximum asymmetry and draw a line showing the position of spine. Similarly take measurements at two points above the point of maximum asymmetry and draw another line showing the position of spine. The intersection of these lines would give the angle of spinal curvature which can be geometrically measured. Fortran program COB.FOR is written and tested to calculate this angle from measurements performed on moire topograph of back.

Fig. 2 (reproduced by permission) shows a thoracolumbar curve of 37° measured from X rays (Fig. 1(b) of Willner, 1979). Measurements performed on moire topograph give CE = 13.5mm, CH = 2.6mm, BF = 3.0mm, BI = -1.5mm, AD = 3.75mm, AG = -3.75mm, AC = 24.0mm, CB = 22.1mm, d_1 = 8.05mm, d_2 = 0, d_3 = 0.75mm, $\Theta = \tan^{-1}(8.05/24.0) + \tan^{-1}(7.3/221) = 36.8°$.

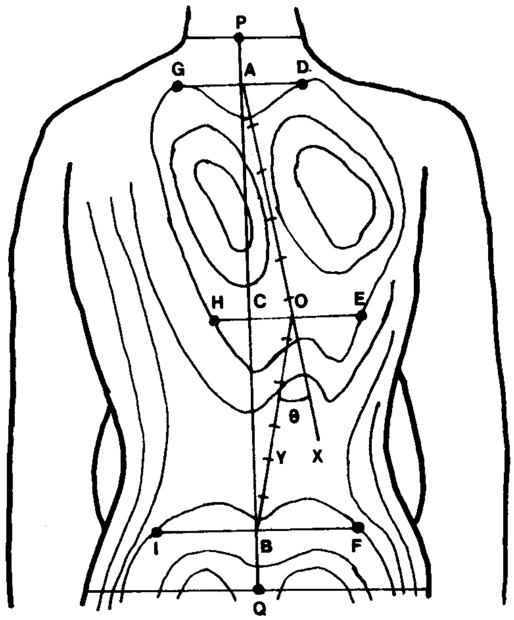

Figure 1.
Cobb's angle measurement from moiré topograph of the back

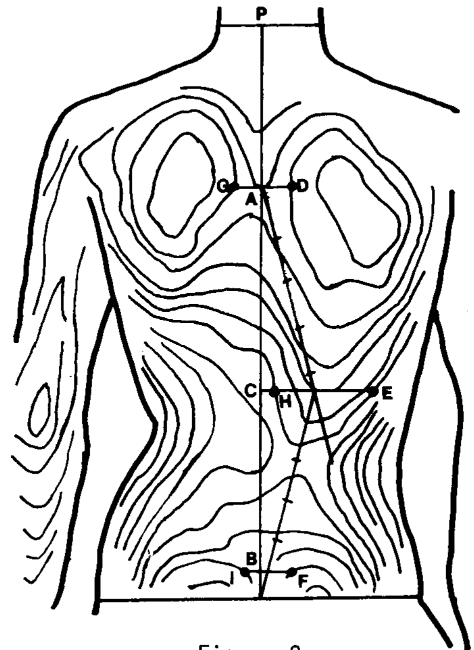

Figure 2.
Thoracolumber scoliosis of 37°

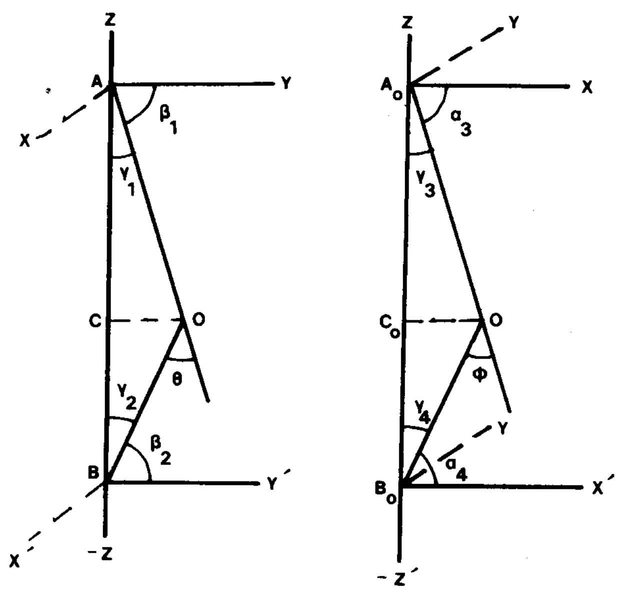

Figure 3.
Projections of spine in yz- and xz-planes

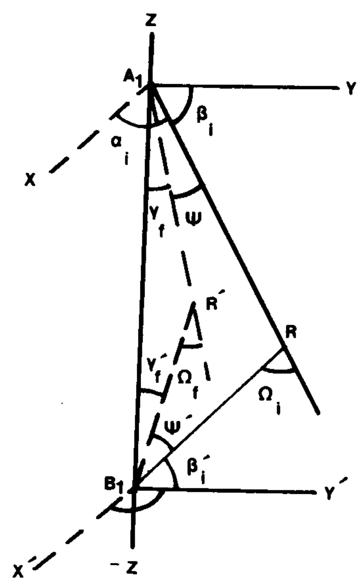

Figure 4.
Spine shown in three dimensions

In Fig 4. $\alpha_i = \angle XA_1R$, $\alpha_i' = \angle X'B_1R$, $\beta_i = \angle YA_1R$, $\beta_i' = \angle Y'B_1R$

$\gamma_i = \angle B_1A_1R$, $\gamma_i' = \angle A_1B_1R$, $\alpha_f = \angle XA_1R'$, $\alpha_f' = \angle X'B_1R'$

$\beta_f = \angle YA_1R'$, $\beta_f' = \angle Y'B_1R'$, $\gamma_f = \angle B_1A_1R'$, $\gamma_f' = \angle A_1B_1R'$

3. Asr Angle Measurement

Consider vectors $\overline{ML}$ and $\overline{ML}_0$ making angles α and α_0 with x-axis, β and β_0 with y-axis, γ and γ_0 with z-axis, respectively. If $\phi = \angle LML_0$ we have

$$\cos\phi = \cos\alpha \cos\alpha_0 + \cos\beta \cos\beta_0 + \cos\gamma \cos\gamma_0 \tag{6}$$

Projections of $\overline{ML}$ on x-, y-, z-axes and xy-, yz-, zx-planes are

$$(ML)_x = ML \cos\alpha, \ . \ . \ . \ , (ML)yz = ML \sin\alpha, \ . \ . \ . \tag{7}$$

Angle of lateral deviation of spine Θ is measured from posterio-anterior roentenogram. Fig. 3 gives

$$\Theta = \gamma_1 + \gamma_2, \ \beta_1 + \gamma_1 = 90° = \beta_2 + \gamma_2, \ \alpha_1 = 90° = \alpha_2 \tag{8}$$

A lateral roentgenogram will give information about kyphosis or lordosis (Fig. 3).

$$\Theta = \gamma_3 + \gamma_4, \ \alpha_3 + \gamma_3 = 90° = \alpha_4 + \gamma_4, \ \beta_3 = 90° = \beta_4 \tag{9}$$

The above are projections of spine in yz- and xz-planes. If we consider spine in three dimensions (Fig. 4), we have

$$\Omega_i = \gamma_i + \gamma_i' \tag{10}$$

Ω_i is called 'Normal Asr Angle' (NAA) which is measured when the subject is standing. Spinal deformity may be partially or completely corrected if the patient is asked to hang freely from a bar in the wall (El-Sayyad and Kamal, 1981). Angle is again measured after guarded graduated passive correction. 'Corrected Asr Angle' (CAA) is, therefore, given by

$$\Omega_f = \gamma_f + \gamma_f' \tag{11}$$

Let $\Psi = \angle RA_1R'$, $\Psi' = \angle RB_1R'$ be the angles between old and new spinal positions. Using eq. 6 we can write (Fig. 4)

$$\cos\Psi = \cos\alpha_i \cos\alpha_f + \cos\beta_i \cos\beta_f + \cos\gamma_i \cos\gamma_f \tag{12a}$$

$$\cos\Psi' = \cos\alpha_i' \cos\alpha_f' + \cos\beta_i' \cos\beta_f' + \cos\gamma_i' \cos\gamma_f' \tag{12b}$$

The degree of correction of spinal deformity is classified as severe, intermediate or mild if D lies between 0-33.33, 33.34-66.66 or 66.67-100 respectively. α_i, β_i, α_i', β_i' can be obtained by using the relations

$$\cos\alpha_i = \tan\gamma_3/(\tan^2\gamma_1 + 1 + \tan^2\gamma_3)^{\frac{1}{2}} \tag{14a}$$

$$\cos\beta_i = \tan\gamma_1/(\tan^2\gamma_1 + 1 + \tan^2\gamma_3)^{\frac{1}{2}} \tag{14b}$$

$$\cos\alpha_i' = \tan\gamma_4/(\tan^2\gamma_2 + 1 + \tan^2\gamma_4)^{\frac{1}{2}} \tag{15a}$$

$$\cos\beta_i' = \tan\gamma_2/(\tan^2\gamma_2 + 1 + \tan^2\gamma_4)^{\frac{1}{2}} \tag{15b}$$

Proof of the above relations is given elsewhere (Kamal, 1982a; b). Moiré topograph of the side (with hand excluded) gives information about kyphosis and lordosis. For side topograph d_1, d_2 and d_3 in eq. 5 are replaced by d_4, d_5 and d_6 respectively (see Figures 3 and 5).

$$\tan\gamma_3 = |d_4 - d_5|/A_0C_0, \ \tan\gamma_4 = |d_4 - d_6|/C_0B_0 \tag{16}$$

We are using A, B, C for moire topograph of back and A_0, B_0, C_0 for side.

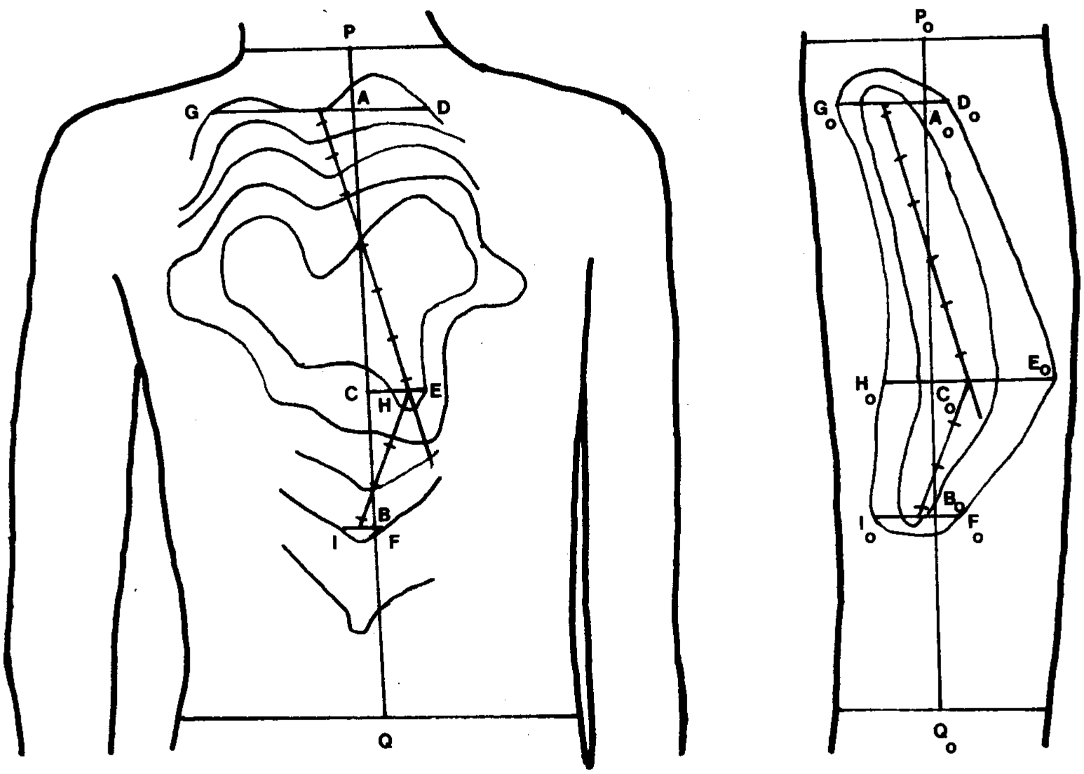

Figure 5.
Moire topograph of back and side in the standing position

Different scales are avoided by using

$$P_1 = (AC + CB)/(A_oC_o + C_oB_o) \tag{17a}$$

$$A_1C_1 = P_1(A_oC_o),\ C_1B_1 = P_1(C_oB_o) \tag{17b}$$

AC and A_oC_o are replaced by A_1C_1, CB and C_oB_o by C_1B_1. Therefore equations (14) and (15) can be written as

$$\cos\alpha_i = |d_4 - d_5|/[(d_1 - d_2)^2 + (A_1C_1)^2 + (d_4 - d_5)^2]^{\frac{1}{2}} \tag{18a}$$

$$\cos\beta_i = |d_1 - d_2|/[(d_1 - d_2)^2 + (A_1C_1)^2 + (d_4 - d_5)^2]^{\frac{1}{2}} \tag{18b}$$

$$\cos\gamma_i = (1 - \cos^2\alpha_i - \cos^2\beta_i)^{\frac{1}{2}} \tag{18c}$$

$$\cos\alpha_i' = |d_4 - d_6|/[(d_1 - d_3)^2 + (C_1B_1)^2 + (d_4 - d_6)^2]^{\frac{1}{2}} \tag{19a}$$

$$\cos\beta_i' = |d_1 - d_3|/[(d_1 - d_3)^2 + (C_1B_1)^2 + (d_4 - d_6)^2]^{\frac{1}{2}} \tag{19b}$$

$$\cos\gamma_i' = (1-\cos^2\alpha_i' - \cos^2\beta_i')^{\frac{1}{2}} \tag{19c}$$

After guarded graduated passive correction, we have

$$\cos\alpha_f = |d_4' - d_5'|/[(d_1' - d_2')^2 + (A_1'C_1')^2 + (d_4' - d_5')^2]^{\frac{1}{2}} \tag{20a}$$

$$\cos\beta_f = |d_1' - d_2'|/[(d_1' - d_2')^2 + (A_1'C_1')^2 + (d_4' - d_5')^2]^{\frac{1}{2}} \tag{20b}$$

$$\cos\gamma_f = (1 - \cos^2\alpha_f - \cos^2\beta_f)^{\frac{1}{2}} \tag{20c}$$

$$\cos\alpha_f' = |d_4' - d_6'|/[(d_1' - d_3')^2 + (C_1'B_1')^2 + (d_4' - d_6')^2]^{\frac{1}{2}} \tag{21a}$$

$$\cos\beta_f' = |d_1' - d_3'|/[(d_1' - d_3')^2 + (C_1'B_1')^2 + (d_4' - d_6')^2]^{\frac{1}{2}} \tag{21b}$$

$$\cos\gamma_f' = (1 - \cos^2\alpha_f - \cos^2\beta_f)^{\frac{1}{2}} \tag{21c}$$

. where

$$Q_1 = (A'C' + C'B')/(A_o'C_o' + C_o'B_o') \tag{22a}$$

$$A_1'C_1' = Q_1(A_o'C_o'),\ C_1'B_1' = Q_1(C_o'B_o') \tag{22b}$$

Let the moiré topographs of back and side when the patient is standing look like Figure 5. We have AD = 8.25mm, AG = -15.75mm, CH = 2.25mm, CE = 6.75mm, BF = 0.75mm, BI = -3.75mm, AC = 31.5mm, CB = 15.0mm, d_1 = 4.5mm, d_2 = -3.75mm, d_3 = -1.5mm, A_oD_o = 1.9mm, A_oG_o = -10.1mm, C_oH_o = -5.6mm, C_oE_o = 13.9mm, B_oF_o = 3.4mm, B_oI_o = -7.1mm, A_oC_o = 31.5mm, C_oB_o = 15.0mm, d_4 = 4.15mm, d_5 = -4.1mm, d_6 = -1.85mm, $\cos\alpha_i = 0.2455 = \cos\beta_i$, $\cos\gamma_i = 0.9378$, $\cos\alpha_i' = 0.3482 = \cos\beta_i'$, $\cos\gamma_i' = 0.8704$, $\alpha_i = 75.78° = \beta_i$, $\gamma_i = 20.31°$, $\alpha_i' = 69.63° = \beta_i'$, $\gamma_i' = 29.59°$, $\Omega_i = 49.81°$

Let the moiré topographs of back and side when the patient is hanging freely from a bar in the wall look like Figure 6. We get A'D' = 8.25 mm, A'G' = -15.75mm, C'H' = 3.0mm, C'E' = 4.5mm, B'F' = 0.75mm, B'I' = -3.75mm, A'C' = 31.5mm, C'B' = 15.0mm, d_1' = 3.75mm, d_2' = -3.75mm, d_3' = -1.5mm, $A_o'D_o'$ = 1.9mm, $A_o'G_o'$ = -10.1mm, $C_o'H_o'$ = 12.4mm, $B_o'F_o'$ = 3.4mm, $C_o'E_o'$ = 12.4mm, $B_o'I_o'$ = -7.1mm, $A_o'C_o'$ = 31.5mm, $C_o'B_o'$ = 15.0mm, d_4' = 3.4mm, d_5' = -4.1mm, d_6' = -1.85mm, $\cos\alpha_f = 0.2256 = \cos\beta_f$, $\cos\gamma_f$ =

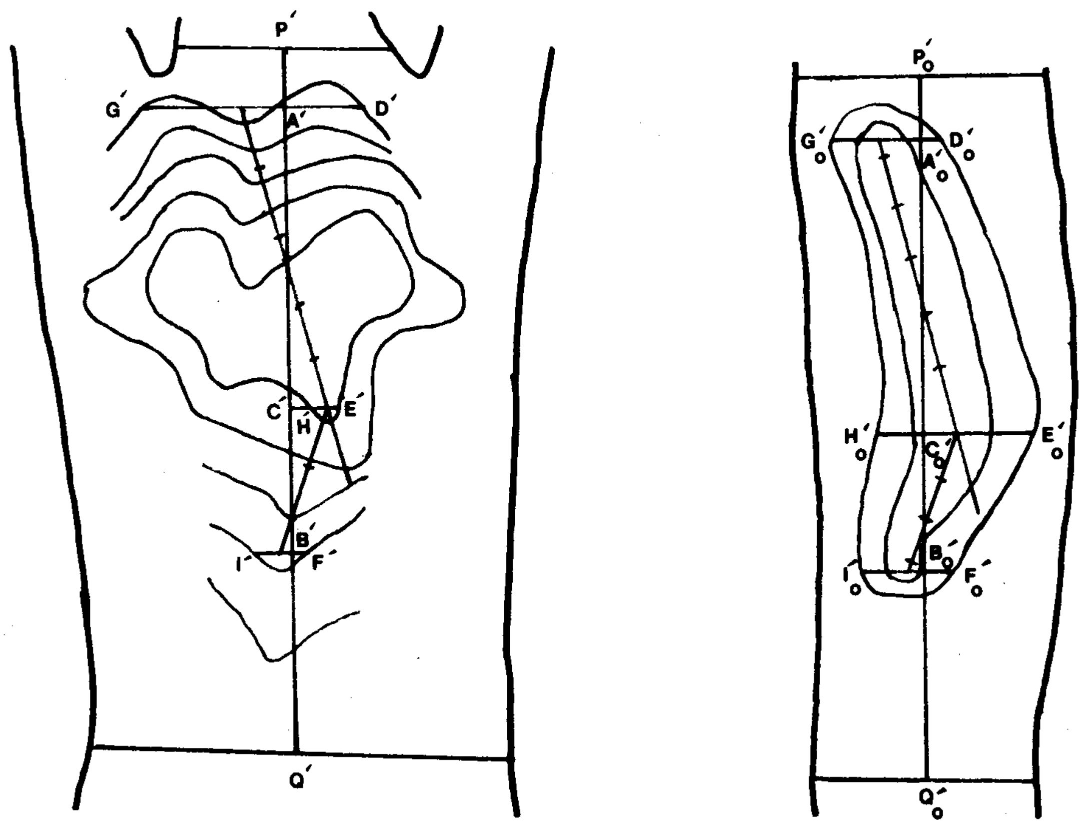

Figure 6.
Moiré topograph of back and side in the hanging position

0.9477, $\cos\alpha_f' = 0.3137 = \cos\beta_f'$, $\cos\gamma_f' = 0.8962$, $\alpha_f = 76.96° = \beta_f$, $\gamma_f = 18.60°$, $\alpha_f' = 71.62° = \beta_f'$, $\gamma_f' = 26.33°$, $\Omega_f = \gamma_f + \gamma_f' = 44.93°$, $\cos\Psi = 0.9995$, $\cos\Psi' = 0.9985$, D = 10.28.

The deformity is, therefore, classified as 'severe'. A fortran program ASR.FOR is written and tested which gives NAA, CAA, D and classifies the deformity as severe, intermediate or mild. The possibility of physiotherapeutic improvement of back deformity can now be quantitatively determined by taking moiré topographs of the patient in the normal and hanging positions.

4. References

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¥ Abstract: http://www.ngds-ku.org/ Papers/C12.pdf

€ Full text: http://www.ngds-ku.org/Papers/J04.pdf

ξ Full text: http://www.ngds-ku.org/Papers/C16.pdf

@ Full text: http://www.ngds-ku.org/Papers/C08.pdf

Note of the editors:

Since there appeared several obscurities concerning the foundations of the methods used in the preceding paper, we asked the author for more thorough explanation. Our questions and the author's answers are quoted below.

Question 1:

In Fig. 1 the term "Cobb angle" is apparently used for angle θ, which represents a certain geometrical feature of the moiré topogram (and not necessarily of the surface shape), but is not in an evident relation to to the usual radiographic Cobb angle. The good coincidence in the example given (Fig. 2) seems to be accidental.

A similar question arises for the evaluation of the moiré topograms of the side (Figs. 5 and 6).

Would you please comment on this?

Answer:

The caption to figure 1 should, preferably, be:

Measurement of the angle of spinal curvature by moiré topographs. It is too early to say about the relationship of θ with Cobb or Risser - Ferguson angle. This can be determined only after a number of studies are done testing the correlation. I, however, tried to measure the angles in cases reported by Moreland, Barce and Pope (1981) and obtained the following results:

Figure Number	Angle measured from moire topograph	Reported Value
4	06^{o}	07^{o}
5	20^{o}	20^{o}
6	16^{o}	16^{o}
7	9.5^{o}	10^{o}
8	12^{o}	12^{o}

In measuring the above angles I used the information given about the region of curves. The curves were measured by the method (El-Sayyad and Kamal, 1981) described below eq. (5). Note that the method is applicable only for a single curve and assuming the spinal segments of AO and OB to be straight. A more general description in three dimensions assuming arbitrary spinal shape and multiple curves will be given in near future.

Question 2:

What is your exact prescription to determine the respective levels of the lines GA, HE and IF in Fig. 1? What is exactly meant by "maximum asymmetry of moire fringes", especially in cases where the fringes do not look like those of Fig. 1? Apparently, the choice of points H and E in Fig. 2 is inconsistent with the description given in your text ("first moiré fringe to the left and to the right of PQ").

Since the angle θ is critically dependent on the choice of these levels an objective and reliable definition is essential.

Similar remarks apply for the evaluation of side moire topograms (Fig. 5 and 6).

Answer:

The description for E and H in the text is intended for slight deviation. A more general statement is given below:

At the point of maximum asymmetry draw a line perpendicular to the line PQ. This line intersects PQ at C and a particular moire fringe at H and E such that E is always on the right side of H.

The question now is which fringe should be chosen to perform measurements. The fringes near the edge would be inappropriate because of edge effects. If the first fringe is chosen, measurement error would be more significant because CH and CE are small. Therefore a compromise has to be reached regarding the fringe chosen. It would be difficult to judge the points of maximum and minimum asymmetry (Kamal, 1980). This difficulty can be avoided by the method (El-Sayyad and Kamal, 1981) given below eq. (5). It is difficult to find the exact point of maximum asymmetry, but an area of maximum asymmetry can, of course, be judged. Take measurements at two points below the point of maximum asymmetry and draw a line showing the position of the spine. Similarly take measurements at two points above the point of maximum asymmetry and draw another line showing the position of spine. The intersection of these lines would give the angle of spinal curvature. The point of intersection of these lines is point O (see fig. 1). This procedure is based on the assumption that AO and OB are straight segments of spine bent at angle θ at the point O.

Question 3:

In eq. (10) angles γ_i and γ_i' are used which are not defined in the corresponding Fig. 4. Likewise, a definition of D (Degree of correction or degree of spinal deformity?) is missing. Thus, it is difficult to judge the practical meaning of your results. Could you give a simple and perspicuous geometrical interpretation of your calculations in regard to the shape of the body surface?

Answer:

$\gamma_i = \angle B_1 A_1 R$, $\qquad \gamma_i' = \angle A_1 B_1 R$

Eq. (13) is missing in the manuscript which defines the degree of correction of spinal deformity D as

$$D = 100\,(\sin\psi + \sin\psi')/(\sin\gamma_i + \sin\gamma_i') \qquad (13)$$

Geometrically if $\psi = 0 = \psi'$, there is no improvement and so D = 0. If $\psi = \gamma_i$, $\psi' = \gamma_i'$, the deformity is completely corrected and so D = 100.

Moreland, M.S., Barce, C.A., Pope, M.H. (1981), Moiré Topography in Scoliosis: Pattern Recognition and Analysis, Moiré Fringe Topography and Spinal Deformity (ed. by M.S. Moreland et al.), pp. 171-185, Pergamon Press, New York