

A Noninvasive Anthropometric Technique for Measuring Kyphosis and Lordosis

An Application for Idiopathic Scoliosis

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Study Design. Cross-sectional measurement of the sagittal geometry of adolescent idiopathic scoliosis patients.

Objectives. To evaluate the accuracy of a noninvasive anthropometric approach for the measurement of kyphosis and lordosis.

Summary of Background Data. Noninvasive approaches were developed to estimate the sagittal curvatures of the spine. However, the magnitude of the estimation error could be high for an important proportion of patients, which leads to a difficult clinical application.

Methods. The group was composed of 124 female patients with a mean age of 13.5 years (SD 2.7 years) with Cobb angles ranging from 4° to 66°. Kyphosis and lordosis were measured on the lateral radiograph. The spine sagittal curvature of the same patients was also estimated using the spatial localization of skin markers placed overlying the spinous processes. These coordinates served as input into a simple trigonometric model. Data were collected by means of a stereovideographic technique (Motion Analysis Corp., Santa Rosa, CA).

Results. The intraclass correlation coefficient between both approaches was 0.94 for kyphosis and 0.91 for lordosis; the mean absolute differences were 5° (SD 4°) and 6° (SD 6°), respectively. The difference was less than 10° in 91% of the patients for kyphosis, and in 79% for lordosis.

Conclusions. The proposed technique appears to give more representative results than those presented in the literature. It has the advantage of being part of a global noninvasive postural evaluation. Using this approach in a systematic manner could help reduce radiograph exposure while keeping track of the spine sagittal curvatures. [Key words: kyphosis, lordosis, scoliosis, spine, measurement, anthropometry] *Spine* 2000;25:1689-1694

Idiopathic scoliosis (IS) is a deformation of the spine that modifies postural geometry. Because this deformation is three-dimensional, postural changes will occur in the frontal plane and in the sagittal plane. Therefore, the quantification of kyphosis and lordosis has become an important component of patients' evaluation and follow-up. Kyphosis and lordosis of scoliosis patients usually change during growth^{5,23,25}; pathology evolution^{11,12,23} or treatment^{11,12} and frequent evaluation of the sagittal spine

could be required to improve prognosis^{6,17} or treatment.^{11,12,23} However, assessment of kyphosis and lordosis is usually achieved using lateral radiographs and thus involves repetitive exposures to radiation. Previous authors have tried with some success to circumvent this limitation by using noninvasive techniques.^{7,13,16,20,24} None of these studies included a detailed comparison of radiologic and anthropometric measures of kyphosis and lordosis for a large group of patients diagnosed with idiopathic scoliosis.

The objective of this study was to evaluate the accuracy of a noninvasive anthropometric model to estimate sagittal spine curvatures in scoliotic patients and to present its clinical applicability through a strategy that would serve to decrease the number of lateral radiographs.

Methods

Patients. From 1995 to 1998, 127 female patients evaluated at the Spinal Pathology Evaluation Center participated in this study. All of these patients were diagnosed with idiopathic scoliosis by an orthopedist after a clinical and radiologic examination. Three patients were excluded because they had six lumbar vertebrae. The remaining 124 patients were between 6.2 and 18.7 years of age (mean 13.5, SD 2.7). This group included 22 thoracic curves (Th) between 7° and 66°; 41 thoracolumbar (TL) between 4° and 44°; and 5 lumbar (L) between 20° and 30°. Two curvatures were identified for 56 patients, Cobb angles ranging from 3° to 61° and 4° to 65°.

Radiographic Measurements. Kyphosis (K_r) and lordosis (L_r) were measured on the lateral radiograph as required for treatment. No radiographs were obtained for the sole purpose of this study. K_r was measured as the angle between the superior endplate of T2 and the inferior endplate of T12. L_r was evaluated using the inferior endplates of T12 and L5. These limits were chosen to measure the same sagittal curvatures for all patients and to compare the results to the standards suggested in literature. Radiologic evaluation was performed with the subject standing in a foot template to impose a standardized base of support. The arms were positioned slightly in front of the trunk for the radiographs to avoid superimposition of the humerus and the spine.

Noninvasive Measurements. Noninvasive stereovideographic estimations of the sagittal curves of the spine was part of the postural geometry evaluation of the IS patients.⁸ Postural geometry evaluation was also performed with the subject standing in the foot template with the arms slightly abducted to ensure the visibility of all skin landmarks. Postural and radiologic evaluations were done less than 30 minutes apart except

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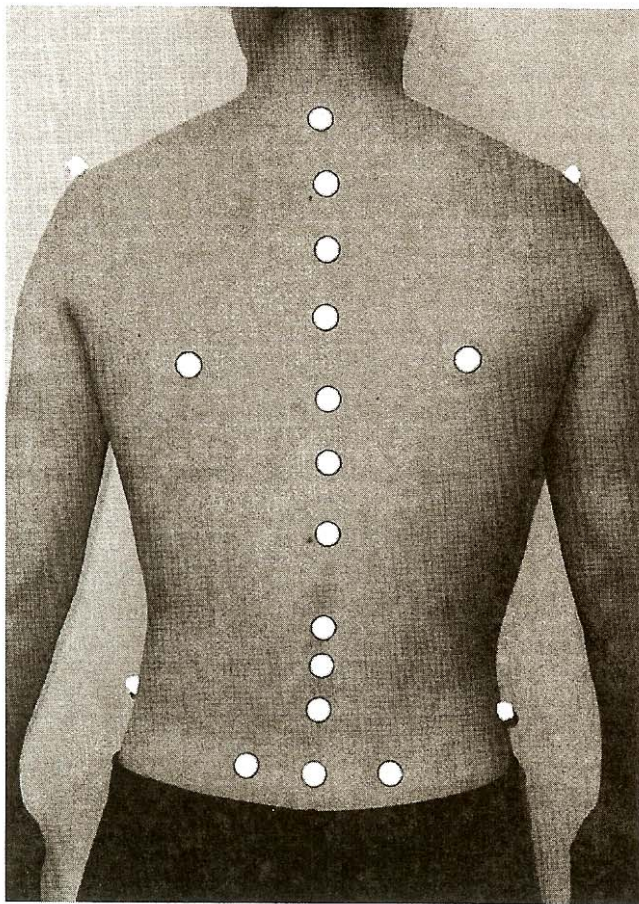


Figure 1. View of a patient's back with reflective markers placed over the spinous processes of T1, T3, T5, T7, T9, T11, L1, L3, L4, L5, and S1. The left and right postero-superior iliac spines, inferior angle of the scapulae, most lateral point of the iliac crests, and acromions were also identified with reflective markers for the postural evaluation.

for 9 patients who had to come back to the clinic for their postural evaluation less than a month later.

The anthropometric estimation of the sagittal curves of the spine is based on the detection of spinous processes and the calculation of their position. The landmarks were detected by palpation and identified with a circular reflective marker (Figure 1). In this study, the spatial coordinates of the spinous processes of T1, T3, T5, T7, T9, T11, L1, L3, L4, L5, and S1 were obtained using a video-based system (Motion Analysis Corp., Santa Rosa, CA). The position of T2 and T12 were linearly interpolated. Anthropometric kyphosis (K_a) and lordosis (L_a) were calculated using the X and Z coordinates as input in a trigonometric equation. For K_a , a line joining T2 and T12 is drawn and a perpendicular (f) is drawn from the farthest spinous process marker (apex) to this line (Figure 2A). This perpendicular line divides the curve of the back in two asymmetric arcs with different radius (Figure 2B). Then K_a is the summation of two angles, φ_1 and φ_2 , that take into account part of the asymmetry of the kyphosis curve, where

$$\varphi_1 = 180^\circ - 2 \times \text{Arctan} (h_1/f) \text{ and } \varphi_2 = 180^\circ - 2$$

$$\times \text{Arctan} (h_2/f)$$

L_a is calculated in a similar way using T9 and S1 markers as the limits of the curve. At first, T12 and L5 were respectively used

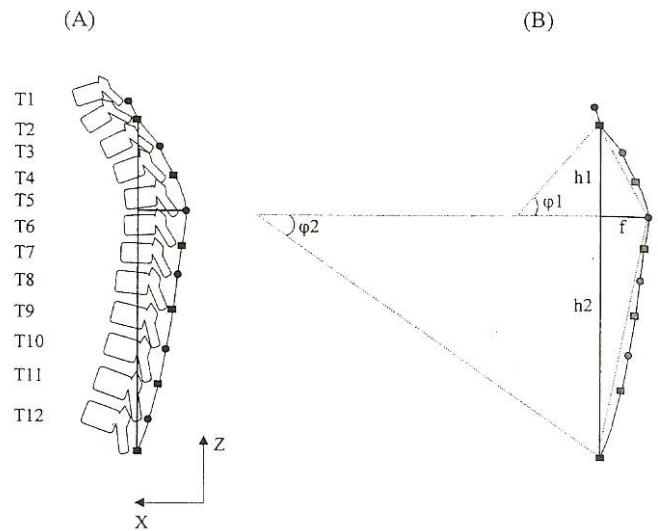


Figure 2. Lateral view of the thoracic spine. **A**, The relationship between the spine and the skin markers used to delimit the kyphosis. **B**, The trigonometric model is based on the calculation of two different angles that reflect the asymmetry of the kyphosis geometry.

as the superior and inferior limit. However, the correlation with the radiologic measure of lordosis was quite weak. It was postulated that the distance between T12 and L5 was too small, so this approach was not representative of radiologic lordosis. The best correlation was obtained using T9 and S1 as the anthropometric limits of the lordosis.

Statistical Analysis. Statistical analysis was performed on a compatible personal computer with Statistica Software (StatSoft, Inc., Tulsa, OK). The relationship between radiographic and anthropometric measures was first assessed with descriptive statistics such as the mean relative difference, standard deviation and range, the mean absolute difference and standard deviation, and the results distribution. Then Pearson's correlation and intraclass correlation coefficients (ICC) were calculated. Regression analysis was also performed for kyphosis and lordosis. The intercept definition was included in the model but not set to (0,0) because both approaches do not measure the curvature in the exact same way.

■ **Results**

Radiologic kyphosis and lordosis were taken as the exact measure of spinal curvatures. The anthropometric evaluation of both curves of the spine was not always possible. Sometimes the image of T9 or T11 reflective markers were occulted because of the overlapping of the bra strap worn by patients. From the postural evaluation, 116 measures of kyphosis and 105 measures of lordosis were obtained. The results are summarized in Table 1.

Kyphosis

The group mean, standard deviation (SD), and range are very similar for both types of measurements. There is a good relationship between K_r and K_a as reflected by small relative (3°) and absolute (5°) mean differences and by a strong correlation coefficient ($r = 0.89$). The intra-

Table 1. Radiologic (K_r and L_r) and Anthropometrical (K_a and L_a) Kyphosis and Lordosis Measurements

	n	Radiologic Mean (SD)	Anthropometric Mean (SD)	Difference Mean (SD)	Absolute Difference Mean (SD)	≤5° n	5° < × ≤ 10° n	>10° n
Kyphosis range	116	33° (10°) 10° to 63°	36° (12°) 8° to 67°	3° (5°) -11° to 17°	5° (4°)	65	40	11
Lordosis range	105	52° (13°) 22° to 90°	51° (17°) 5° to 96°	-1° (8°) -27° to 22°	6° (6°)	57	26	22

SD = standard deviation.

class correlation coefficient is 0.94, showing good agreement between both approaches. More than half the patients (56.0%) show a difference of less than 5°, 90.5% of less than 10°. The mean absolute difference in the location of the apex of K_r and K_a is 0.8 vertebral level (SD 0.8 level; range from 2 levels below to 3 levels above).

The regression analysis supports the agreement between both measurements (Figure 3). Even if the 5.58 intercept and the 0.76 slope of the least square estimation show that the anthropometric and radiologic approaches are not identical, the standard error of estimation (4.5°) underlines the accuracy of K_a in predicting real kyphosis. On Figure 3, data collected from 102 control subjects by Bernhardt et al¹ were used to arbitrarily set a range of normal kyphosis, defined by the mean \pm 2 SD (36° \pm 2 \times 10°). Horizontal dot lines were then drawn at 16° and 56° for K_r and vertical lines at 14° and 67° for K_a . Both measurements are in good agreement for 109 patients ("A" zones). For seven patients, K_a is different from the radiograph measurement ("B" and "C" zones).

Lordosis

The group mean and SD are similar for both types of measurements, but the range of L_a is larger, showing a lower inferior limit. There is also a good relationship

between L_r and L_a as reflected by small relative (-1°) and absolute (6°) mean differences and by a strong correlation coefficient ($r = 0.84$). The ICC is 0.91, showing good agreement between both approaches. More than half the measurements (54.3%) show a difference of less than 5°, 79% of less than 10°. There are more patients with a difference higher than 10° for lordosis²² as compared with kyphosis.¹¹ The mean absolute difference between the apex location for lordosis is also 0.8 vertebral level (SD 0.8 level; range from 3 levels below to 1 level above). The smaller correlation coefficient (0.85) and the regression analysis (Figure 4) support the fact that the relationship between lordosis measurements is less direct than for kyphosis. The intercept of 15.42 represents a large bias of L_a measurements, but a slope of 0.721 and a standard error of estimation of 7.2° show that predicting lordosis from the anthropometric measurements is still quite accurate. As for kyphosis, data collected by Bernhardt et al¹ were used to define normal lordosis as the mean \pm 2 SD (44° \pm 2 \times 12°). On Figure 4, horizontal dot lines were then drawn at 20° and 68° for L_r and vertical lines at 6° and 73° for L_a . Both measurements are in good agreement for 98 patients ("A" zones). For eight patients, L_a is different from lateral radiograph measurements ("B" and "C" zones).

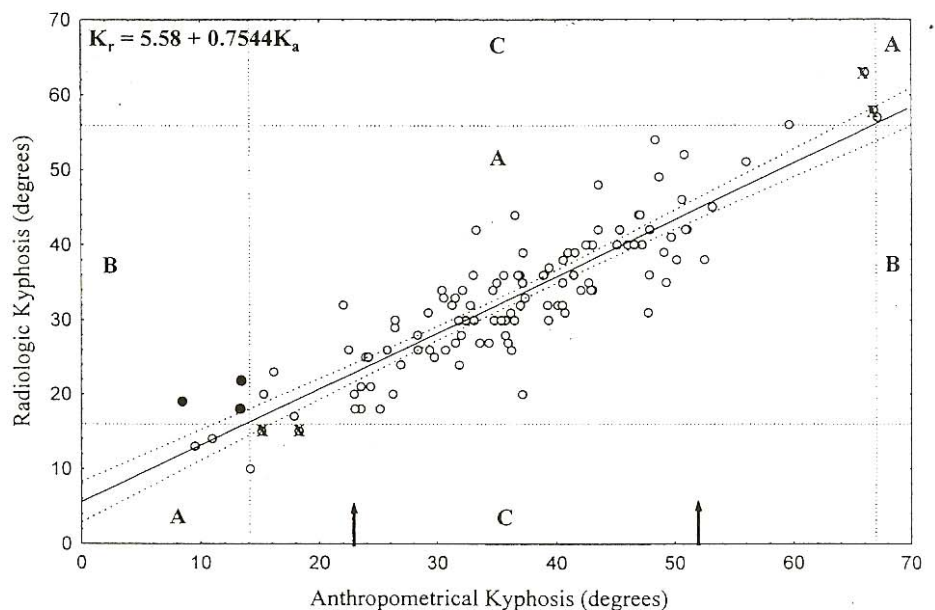


Figure 3. Distribution of anthropometric estimation of kyphosis in relation to the standard radiographic measurement. Regression line is shown with the 95% confidence intervals (dashed lines). Vertical and horizontal dotted lines represent the distribution of control subjects (from Bernhardt et al¹) and divides the figure in 9 zones. The same results are obtained with both approaches in "A" zones (○), false-positives (●) are regrouped in "B" zones; false-negatives (X) are regrouped in "C" zones.

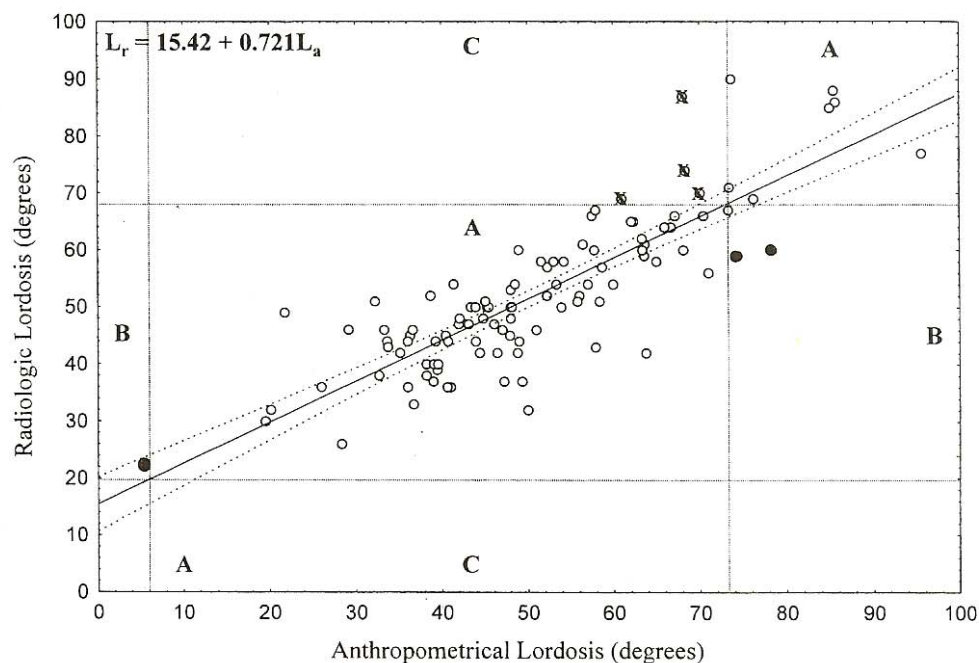


Figure 4. Distribution of anthropometric estimation of lordosis in relation to the standard radiographic measurement. Regression line is shown with the 95% confidence intervals (dashed lines). Vertical and horizontal dotted lines represent the distribution of control subjects (from Bernhardt and Bridwell¹ and divides the figure into 9 zones. The same results are obtained with both approaches, in "A" zones (○); false-positives (●) are regrouped in "B" zones; false-negatives (X) are regrouped in "C" zones.

Discussion

The main objective of this study was to evaluate the accuracy of a noninvasive anthropometric approach for the estimation of sagittal spine curvatures in scoliotic patients. Anthropometric kyphosis (K_a) and lordosis (L_a) were developed to match the conventional radiologic parameters and to describe the relationship between back surface and spine geometry. Radiologic kyphosis (K_r) and lordosis (L_r) were considered as the standard measurement even if a $\pm 5^\circ$ error is generally accepted.^{4,10,14,19} The correlation coefficients demonstrate a strong relationship between both approaches for kyphosis ($r = 0.89$) and lordosis ($r = 0.84$). The relative mean differences between anthropometric and radiologic data are small for kyphosis (3°) and lordosis (-1°), but the range of values is quite wide, respectively, -11° to 17° and -27° to 22° . Even then, the intraclass correlation coefficient supports the good agreement between both measurements of kyphosis (ICC = 0.94) and lordosis (ICC = 0.91).

The amplitude of the frontal Cobb angle does not seem to be a factor that explains the marked difference noted for certain patients since it is not significantly correlated with the difference in measurement for kyphosis ($r = -0.15$) and lordosis ($r = -0.20$). The patients who had a difference larger than 10° did not belong to a specific class or have a different Cobb angle amplitude. The 33° mean kyphosis (SD 10°) and the 52° mean lordosis (SD 13°) measured for the 124 IS patients are comparable with the 24.9° to 36.9° kyphosis and the 33.7° to 48.5° lordosis values obtained in previous studies.^{7,15,18,20,22,24-26} However, several other factors could explain the larger discrepancies noted for specific cases. The first two were methodologic and are related to missing data from the even thoracic vertebrae and L2

and to the choice of the same curve limits for all patients. Landmarks localization could also affect to a lesser extent the relationship between both measurements. Other factors^{9,21} could be related to the morphology of the patients such as increased adiposity, T2 geometry, L5 wedging, or S1 more vertical.

The estimation of kyphosis and lordosis based on the data collected in this study seems to be more accurate than estimation done using other reported anthropometric techniques. Willner,²³ using a spinal pantograph, was the first author to demonstrate a relationship between surface geometry and radiographs. Kyphosis and lordosis were measured as angles between tangents to the image of the back curves. The correlation with radiographic measures was very good for kyphosis ($r = 0.97$) but lower for lordosis ($r = 0.80$). The mean relative difference reported is 0° , but no other information could confirm the agreement between both techniques. Stokes and Moreland²⁰ reported data collected using Moiré Topography and, as for Willner,²⁴ tangents to the back shape were used to calculate kyphosis and lordosis. Mean differences from radiograph measurements were quite small— 0.9° for kyphosis and 1.7° for lordosis—but no specific analysis was performed to compare both sets of data. Mellin¹³ used a Myrin inclinometer to measure kyphosis and lordosis. However, no relation was established with the same parameters measured on radiographs. The absence of radiographic comparison could also be applied to the study by Öhlén et al¹⁶ who used Debrunner's kyphometer to estimate the sagittal curvatures.

D'Osualdo et al⁷ collected kyphosis data with the Arcometer (Udine University, Engineering Faculty, Udine, Italy) and used a trigonometric model similar to the one presented here. However, the reproduction of calcula-

tions was not accurate. The kyphosis angle should not be “arcsin (chord/radius)” but “ $2 \times \arcsin(\text{chord}/[2 \times \text{radius}])$.” The mean difference between the Arcometer and the radiography was 3° , which is similar to the difference calculated in this study (3° ; SD 6°) but with a larger standard deviation of 9° . This reflects the 30% of patients with a difference of more than 10° as compared with the 12% reported here.

The main difference between both approaches is related to the fact that D’Osueldo et al modeled the curvature of the back using a single arc. It seems obvious that it is not the case since the rise of the arc (f) is not always in the middle of the chord (Figure 2). In this study, two different radius were used to calculate the kyphosis angle. The mean absolute differences between φ_1 and φ_2 is 4° (SD = 5°) with differences as large as 22° . Using only 1 arc, the correlation with radiographic measures is lower (0.78) with higher mean absolute difference (8° ; SD 7°), so the approach presented here seems to be more representative of the underlying geometry.

Clinical Application

The authors agree with D’Osueldo et al⁷ that the use of correlation and regression analysis reflects the relationship between both approaches but not the agreement² between them. The intraclass correlation coefficient gives a better idea on this aspect,³ but it is still difficult to analyze the accuracy of a noninvasive technique from a clinical point of view. Figures 2 and 3 are drawn in a way to help the clinician in his decision. The graph is divided into nine sections using a range of accepted normality. Patients that fall in “A” sections are categorized the same way with both tools. Patients of “B” sections are false-positives because their anthropometric evaluation is out of the range of normality but the measure on the radiographs falls within the normal range. Patients of “C” sections are false-negatives because they are considered as normal using the postural evaluation, but true spinal curvature values are higher or lower than the normal standards.

Regarding this information, a clinical strategy could be proposed. It is suggested that the postural evaluation be performed first. If the kyphosis or lordosis calculated falls out of the normal range, lateral radiographs must be taken to validate the diagnostic and reach for more information about the sagittal spine geometry. Depending on the resources, level of radiograph exposure accepted by the clinician, and specific applications, limits of the anthropometric normal ranges could be set to the desired values. If the anthropometric normal range is narrow, the number of necessary radiographs will increase in parallel with irradiation and cost. Conversely, if the range is too wide, some pathologic state could be missed.

For example, it should be noted in Figure 3, that using this specific normal range, three patients are false-positives (●) and four patients are false-negatives (X). To avoid false-negatives, discrepancies between anthropometric and radiographic measurements should be taken into account. Limits of agreement² could be calcu-

lated to fix a new range of normality for K_a . For a 95% confidence interval, a specific K_a estimates K_r in a range between -7° and 15° . The corrected lower normal value of K_a (\uparrow) will then be 21° ($14^\circ + 7^\circ$) and the higher normal value 52° ($67^\circ - 15^\circ$). Using K_a ranging from 21° to 52° as normal values, the clinician could be confident (95%) that no pathologic kyphosis will be missed using anthropometric evaluation. On the other side, more false-positives will be obtained. In Figure 3, the number of false-negatives would go from 4 to 0 and the number of false-positives increases from 3 to 9.

Conclusion

The advantage of the model and the technique presented in this study depends on its noninvasive aspect, the time needed for evaluation, and its integration in a complete postural evaluation.⁷ This approach was not developed to replace radiographs from which much more information than kyphosis and lordosis measurements could be drawn. However, a specific strategy could be used during screening and follow-up to reduce patient irradiation, evaluation time, and cost and should be further developed.

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Key Points

- The sagittal curvatures of the spine were estimated using an anthropometric approach.
- Radiographic and anthropometric evaluations of 124 idiopathic scoliosis patients were performed.
- Kyphosis and lordosis measures obtained using each approach were compared.
- The anthropometric measurements were used in relationship with normal subjects’ values.

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