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Estimated Kyphosis and Lordosis Changes at Follow-Up in Patients With Idiopathic Scoliosis

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Summary: The objective of this study was to verify the accuracy of surface measurements to estimate the magnitude of sagittal curvature changes at follow-up. Ninety-seven patients with idiopathic scoliosis were evaluated at two different visits (interval: 15.7 months). Kyphosis and lordosis were measured on the lateral radiograph. Surface measurements rely on localization of spinous process landmarks using a video-based system. Multiple regression analyses were performed to estimate the sagittal curvatures on the second visit. The regression was significant for both kyphosis and lordosis. The mean absolute difference between the estimate and the radiologic measurement was 3.3° for kyphosis and 3.2° for lordosis. The difference between the estimated change and the observed change between visits showed mean absolute differences of 3.4° and 2.7°, respectively. The proposed strategy could be used during follow-up to reduce patient irradiation without loss of sagittal information. **Key Words:** Follow-up—Kyphosis—Lordosis—Scoliosis—Spine—Surface measurements.

Vertebral deformation and disorientation of the scoliosis spine are three-dimensional in nature and therefore have an impact on the sagittal configuration of the spine (7,15,17,23). However, the lateral radiograph is often omitted during patient follow-up. In addition to the invasiveness of the evaluation, the availability of radiology, the cost of the evaluation, and the time spent to analyze each radiograph represent important limitations for clinicians. Solutions have been developed based on the use of noninvasive surface measurements to estimate the magnitude of kyphosis and lordosis (5,14,16,22). In particular, Leroux et al. (12) have shown a satisfactory relationship between radiologic measurements and surface estimates. This relationship stands for a single-visit comparison, but there is no information about the accuracy of this approach for the follow-up of patients with scoliosis. The objective of this study was to verify the accuracy of surface measurements to estimate the magnitude of sagittal curvature changes at follow-up.

METHODS

In this study, 97 patients with idiopathic scoliosis were evaluated at the Spinal Pathology Evaluation Center between 1995 and 2000. The group comprised 83 girls and 14 boys. Age at the initial visit was 6 to 17 years, with an average of 12.6 years with a standard deviation (SD) of 2.4 years. There were 25 thoracic curves with a mean Cobb angle of 23.2° (SD 13.1°), 39 thoracolumbar curves with a mean Cobb angle of 17.0° (SD 9.7°), 7 lumbar curves with a mean Cobb angle of 24.7° (SD 6.4°), and 26 doubles with mean Cobb angles of 24.9° (SD 9.9°) and 26.9° (SD 9.4°). Among this group, 54 patients were treated with the SpineCor brace and 43 patients did not receive any treatment between the visits. The mean interval between the two visits was 15.7 months (SD 8.6).

The radiologic parameters, kyphosis (K_r) and lordosis (L_r), were measured on a lateral radiograph. No radiograph was taken for the sole purpose of this study. The position of the patient for the radiologic and surface evaluations was standardized using a foot template. Arm position was slightly different to ensure the visibility of all landmarks. For the radiologic evaluation, the arms were completely flexed at the elbow and in front of the trunk to avoid superimposition of the humerus and the spine. The arms were straight and slightly abducted during the postural evaluation.

On the radiograph, K_r was measured as the angle between the superior endplate of T2 and the inferior endplate of T12. L_r was quantified using the inferior endplates of T12 and L5. These limits were chosen to measure the same sagittal curvatures for all patients according to standards suggested in the literature. A change

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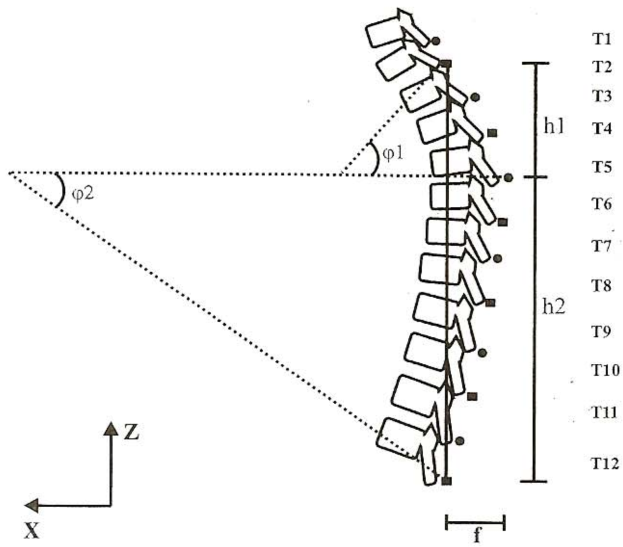

FIG. 1. Lateral view of the skin landmarks identifying the spinous processes of the patient. Kyphosis (K_a) is estimated based on the calculation of φ_1 and φ_2 angles.

in curve magnitude of at least 5° degrees was considered clinically significant. This decision was based on the radiologic measurement variations, mean, and standard deviation reported in the literature (3,9).

The calculation of the surface parameters (12), kyphosis (K_a) and lordosis (L_a), was based on the three-dimensional coordinates of anatomic landmarks identified for the postural evaluation. A video-based system (Motion Analysis Corp., Santa Rosa, CA, U.S.A.) was used to record and process the data. Reconstruction error was estimated to 1 mm. Surface measurements used in this study are the average of two or three acquisitions at 60 Hz.

The surface kyphosis (K_a) and lordosis (L_a) were calculated using the sagittal coordinates of the T1, T3, T5, T7, T9, T11, L1, L3, L4, L5, and S1 spinous processes. The complete technique has previously been described (12). For K_a, a line joining T2 and T12 (linearly interpolated) and a perpendicular is drawn from the apex to this line. This perpendicular divides the curve of the back in two asymmetric arcs with different radii (Fig. 1). K_a is the summation of two angles, φ_1 and φ_2, which form the tips of isosceles triangles:

φ_1 = 180° minus 2 × Arctan (h_1/f) and φ_2 = 180° minus 2 × Arctan (h_2/f)

L_a is calculated in a similar way using T9 and S1 markers as the limits of the curve.

The initial radiographic evaluation is essential to diagnose idiopathic scoliosis, to rule out other etiologies, and to identify bone pathologies. It was paired with an initial postural evaluation to quantify precisely the initial state of the patient. This information was used together with the postural evaluation performed on the subsequent visit to estimate the sagittal curvatures of the spine on this latter visit. A multiple regression analysis was calculated to estimate the K_r of the follow-up visit:

$$K_e = C_0 + C_a * K_{r1} + C_b * K_{a1} + C_c * K_{a2}$$

Where K_e = kyphosis estimate for the follow-up visit, K_{r1} = initial kyphosis measured on the sagittal radiograph, K_{a1} = initial kyphosis estimated using surface measurements, K_{a2} = kyphosis estimated for the follow-up visit using surface measurements, and C_0, C_a, C_b, C_c = coefficients of the multiple regression.

L_r is estimated in a similar way.

In a second step, K_e and L_e were used to estimate the change of curve magnitude from the first visit. The estimated change was then compared with the true change measured on the radiograph.

RESULTS

The surface measurement of both sagittal curves of the spine was not always possible. Sometimes the image of

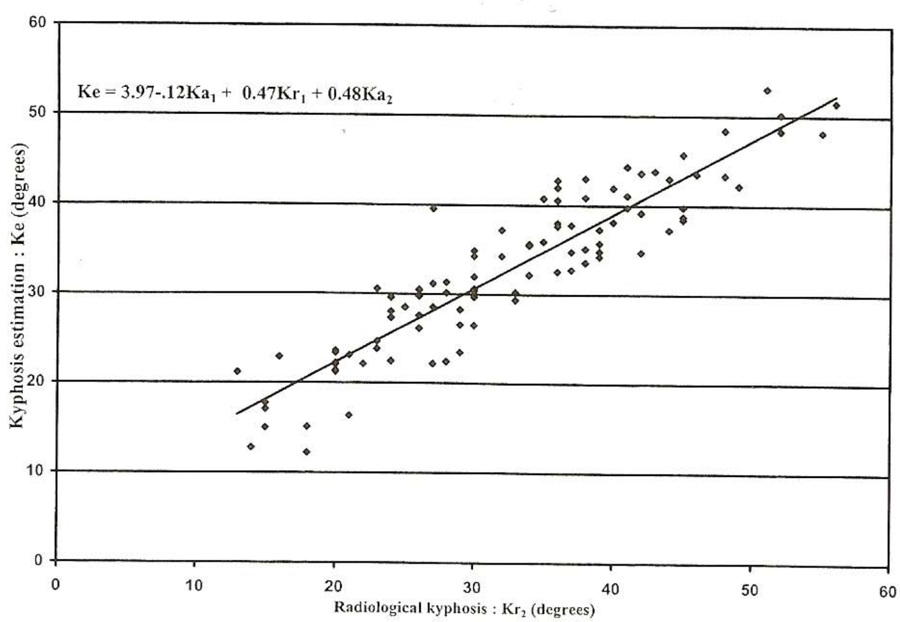

FIG. 2. Relationship between the radiologic measurement of kyphosis on visit 2 (k_{r2}) and the kyphosis estimated (K_e) from surface measurements.

TABLE 1. *Descriptive statistics of radiological and surface measurements of kyphosis*

	K_{r1} (visit 1)	K_{r2} (visit 2)	K_e (visit 2)	$K_e - K_{r2}$	$K_{r2} - K_{r1}$	$K_e - K_{r1}$
Mean (°)	32.6	32.6	32.7	0.2	0	0.1
SD (°)	11.1	10.2	9.2	4.0	5.8	4.2
Range (°)	6 to 58	13 to 56	12 to 53	−7.3 to 12.6	−12 to 16	−9.7 to 8.7
Mean-abs (°)				3.3	4.6	3.4
SD-abs (°)				2.2	3.5	2.5
≤5°				79	61	70
5° ≤ x ≤ 10°				16	29	26
10°				1	6	0

abs, absolute values; SD, standard deviation.
N = 96.

T9 or T11 reflective markers was obscured because of an overlapping bra strap. From the postural evaluation, 96 and 87 patients had complete data for kyphosis and lordosis, respectively.

Kyphosis between-trial variation averaged 2.1° (SD 1.7°) across patients. Kyphosis amplitude at follow-up was estimated (K_c) using a regression analysis that included the initial kyphosis (K_{r1}) and surface measurements (K_{a1} and K_{a2}) on both visits (Fig. 2). This regression was statistically significant ($R^2 = 0.84$, $P < 0.05$) with beta coefficients of −0.16 for K_{a1}, 0.64 for K_{a2}, and 0.49 for K_{r1} ($P < 0.05$). The addition of other predictor parameters such as age, time between visits, or treatment/no treatment did not improve the regression ($P > 0.05$). The descriptive statistics are presented in Table 1. K_{r2} and K_e means, standard deviations, and ranges were very similar, indicating the accuracy of the estimation. The mean absolute difference between both values (K_e minus K_{r2}) was 3.3° (SD 2.2°). From these 96 differences, 79 (82%) were <5°. The difference was 5° to 10° for 16 patients (17%). A single patient (1%) showed a difference <10°.

As shown in Table 1, the between-visits change in kyphosis measured on lateral radiographs (K_{r2} minus K_{r1}) averaged 4.6° (SD 3.5°). It ranged from a 12° decrease to a 16° increase. Thirty-five patients (36%) showed a change of >5°. When the change in kyphosis was estimated using the regression results (K_c minus K_{r1}), the average difference was 3.4° (SD 2.5°). Figure 3 presents the relationship between both approaches. The difference between the radiologic change and the estimated change was 4.4° (SD 3.1°). Of the 35 patients who showed a kyphosis change >5°, 23 patients were identified (66%) but 12 were missed (34%). Of the 59 patients who did not show a significant kyphosis change, 57 were correctly identified as stable (97%), but two were incorrectly declared stable (3%).

Kyphosis between-trial variation averaged 1.7° (SD 1.3°) across patients. Lordosis amplitude at follow-up was estimated (L_e) using a regression analysis that included the initial lordosis (L_{r1}) and surface measurements (L_{a1} and L_{a2}) on both visits (Fig. 4). The regression was statistically significant ($R^2 = 0.86$, $P < 0.05$) with beta coefficients of −0.18 for L_{a1}, 0.42 for L_{a2}, and 0.76 for L_{r1} ($P < 0.05$). As for kyphosis, the addition of other predictor parameters did not improve the accuracy of the regression. The descriptive statistics are presented in Table 2. L_{r2} and L_e means, standard deviations, and ranges were very similar, indicating the accuracy of the estimation. The mean absolute difference between both

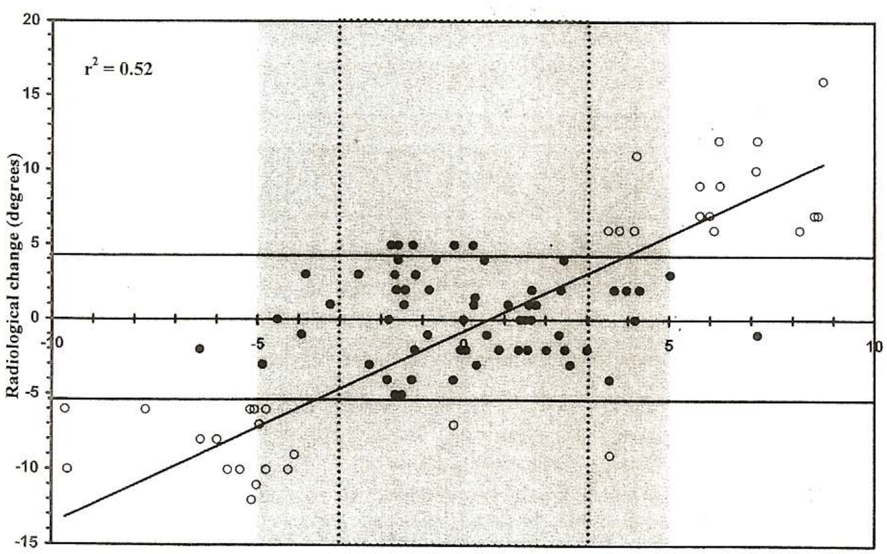

FIG. 3. Relationship between radiologic and estimated kyphosis change between visits. Open symbols, radiologic change >5°; closed symbols, radiologic change 5° or less; shaded area, anthropometric change 5° or less.

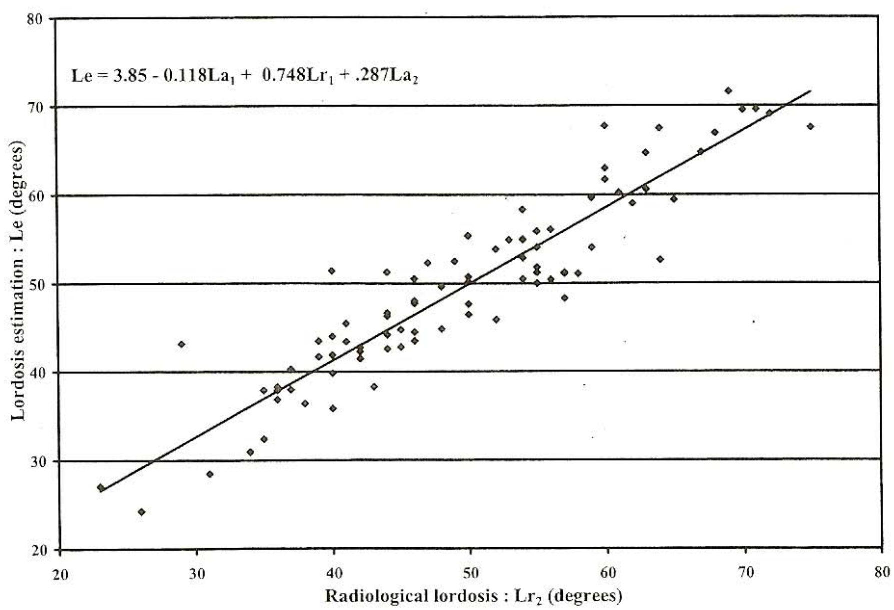

FIG. 4. Relationship between the radiologic measurement of lordosis on visit 2 (L_{r2}) and the lordosis estimated (L_e) from surface measurements.

values (L_e minus L_{r2}) was 3.2° (SD 2.6°). Of these 87 differences, 74 (85%) were <5°. Of the other 16 patients, 10 (11%) were 5° to 10° and 3 (4%) were >10°. As shown in Table 2, the between-visits change in lordosis measured on lateral radiographs (L_{r2} minus L_{r1}) averaged 4.1° (SD 3.0°). It ranged from a 12° decrease to an 8° increase. Twenty-nine patients showed a change of >5°. When the change in lordosis was estimated using the regression results (L_e minus L_{r1}), the average difference was 2.7° (SD 2.1°). Figure 5 presents the relationship between both approaches. The difference between the radiologic change and the estimated change was 3.2° (SD 2.6°). Of the 29 patients who showed a lordosis change >5°, 9 were identified (31%) and 20 were missed (69%). Only 1 of the 58 patients who did not show a significant lordosis change was incorrectly declared stable (2%).

DISCUSSION

The main objective of this study was to verify the accuracy of surface measurements to estimate the sagittal curvatures of patients with scoliosis during their follow-up. The technique was developed (12) to match the conventional radiologic parameters by quantifying the relationship between the surface of the back and the spinal geometry. The present approach proposes adding the initial radiologic measurements to obtain a better estimation of kyphosis and lordosis at the follow-up visits.

The data collected in this study showed that for kyphosis, the mean difference between the estimate and the radiologic measure on the follow-up visit (average 3.3°, SD 2.2°) was smaller than that reported previously by Leroux et al. (12) (average 5°; SD 4°). In the current study, 82% of the kyphosis estimations differed by 5° or less from the radiologic value, as opposed to the 56% previously reported (12). The addition of the initial radiologic measurement in the regression had a large impact on the accuracy of the estimate, as reflected by its strong beta coefficient (0.53). Similar observations were noted for lordosis. The mean difference between the estimate and the radiologic value was 3.2° (SD 2.6°) as opposed to the 6° (SD 6°) previously reported (12). Moreover, 85% of the lordosis estimates differed by 5° or less from the radiologic values, as opposed to 54%. The beta coefficient associated with the initial radiologic

TABLE 2. *Descriptive statistics of radiological and surface measurements of lordosis*

	L_{r1} (visit 1)	L_{r2} (visit 2)	L_e (visit 2)	$L_e - L_{r2}$	$L_{r2} - L_{r1}$	$L_e - L_{r1}$
Mean (°)	49.2	48.9	49.2	0.3	−0.4	−0.1
SD (°)	12.1	10.7	10.2	3.9	5.1	3.5
Range (°)	20 to 76	23 to 72	24 to 72	−6.9 to 11.4	−12 to 8	−6.6 to 8.2
Mean-abs (°)				3.2	4.1	2.7
SD-abs (°)				2.6	3.0	2.1
≤5°				74	58	79
5° ≤ x ≤ 10°				10	26	8
10°				3	3	0

abs, absolute values; SD, standard deviation.
N = 87.

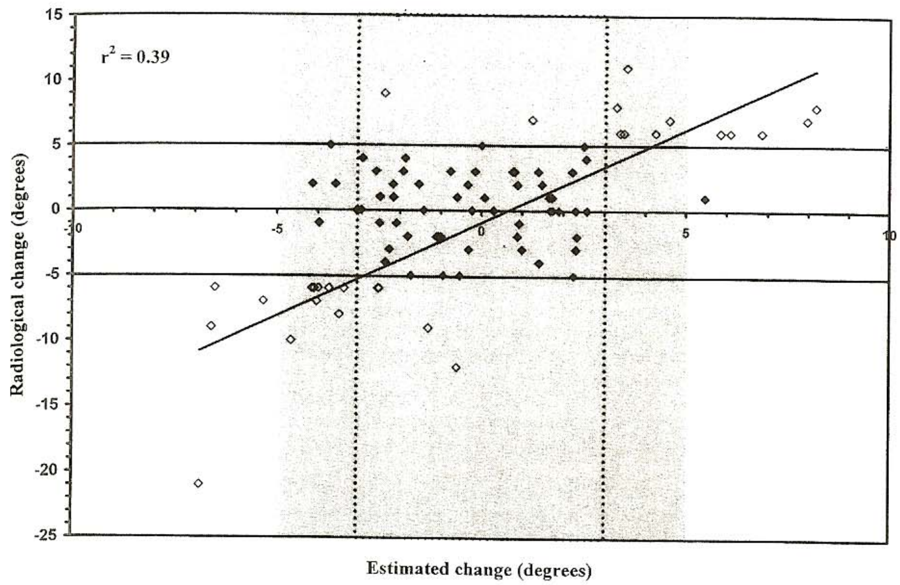

FIG. 5. Relationship between radiologic and estimated lordosis change between visits. Open symbols, radiologic change >5°; closed symbols, radiologic change 5° or less; shaded area, anthropometric change 5° or less.

measurement of lordosis was very strong (0.77). These results should lead to a better estimation of the kyphosis and lordosis curve magnitude at follow-up visits.

However, the change in sagittal curvatures at follow-up represents an important issue for the clinician. The results presented in Figure 3 indicate that if the clinician detects, using surface measurements, a kyphosis increase >5°, the probability that the patient has a true radiologic increase of >5° is 86%. If a decrease of >5° is detected using the regression, the probability that the patient has a true radiologic decrease of >5° is 92%. If no significant change is noted using surface measurements (−5° ≤

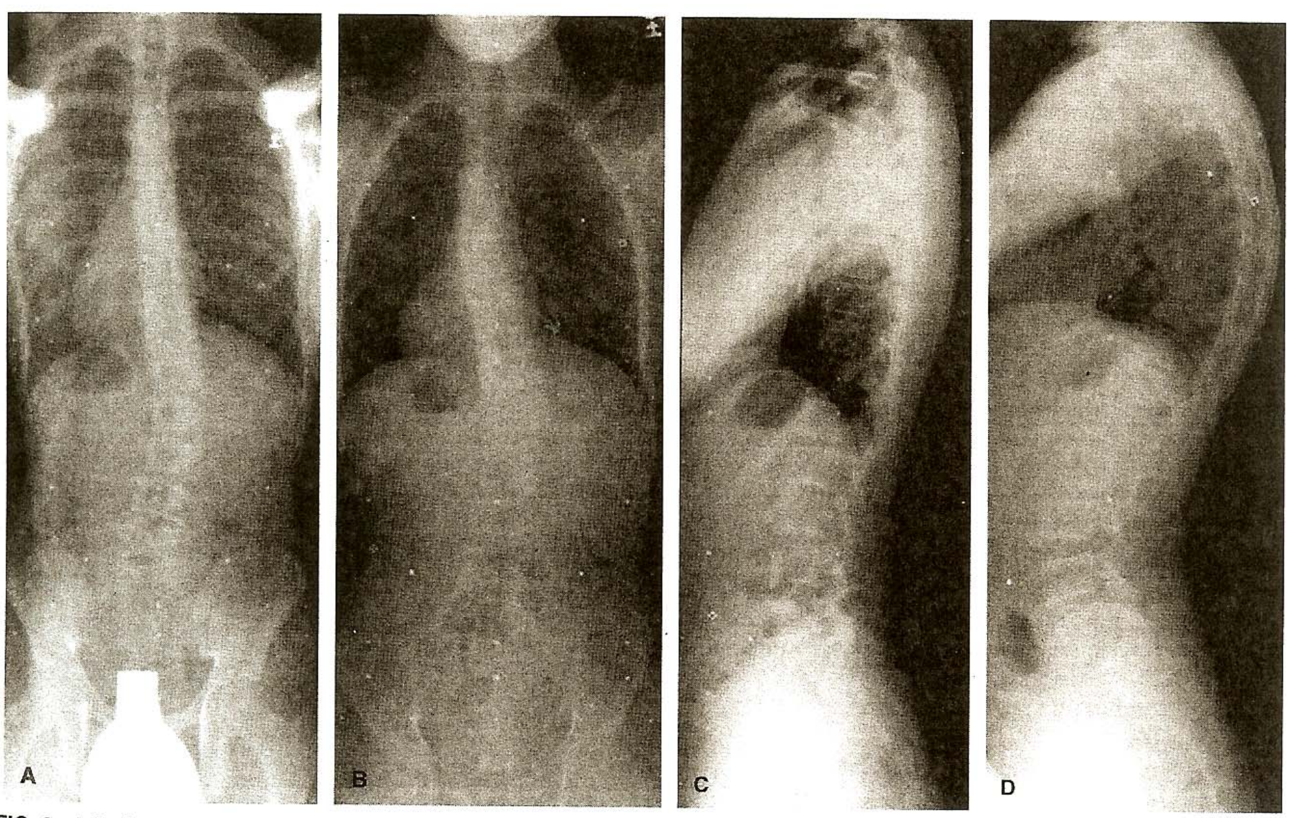

FIG. 6. A-B: Posteroanterior radiographs of two different patients showing similar scoliosis curvatures: right thoracolumbar with an apex at T12 and 25° Cobb angle. **C-D**: Lateral radiographs of the same two patients, showing different sagittal curvatures: kyphosis of 22° and lordosis of 28° (**C**) and kyphosis of 69° and lordosis of 68° (**D**).

change ≤ 5°), the probability that a patient had a radiologic variation of <5° is 83%. That leaves 17%, or 12 patients, with a real change of >5°.

For lordosis, the results presented in Figure 4 indicate that if the clinician detects a lordosis increase using surface measurements, the probability that the patient has a true radiologic increase of >5° is 83%. For a decrease, the probability of a corresponding radiologic decrease is 100%. However, if no significant change is noted using the surface approach, the probability that a patient experienced a radiologic lordosis variation of >5° is 74%. That leaves 26%, or 20 patients, with a real change of >5°.

The lordosis results are less accurate than the kyphosis results. This could be explained, at least in part, by the difference in mobility of the two spinal segments. In the thoracic region, the amplitude of movement in the sagittal plane (flexion–extension) is limited. The lumbar spine mobility in this plane could, however, reach large amplitudes. Lordosis is also dependent on pelvis orientation. This gives more versatility for the patient to adopt several slightly different positions. Because surface and radiologic acquisitions are not simultaneous, the strength of the link between both measurements could be affected.

Several patients showed a radiologic change in their sagittal curvatures and were not identified using surface measurements. The relationship between both approaches, presented in Figures 3 and 5, shows that the coefficient of determination (r^2) was only 0.52 and 0.39 for kyphosis and lordosis change, respectively. This apparent weakness of the model could, however, be improved by setting a different threshold for surface measurements changes. For example, if the clinical objective is to identify a larger number of true curvature changes, the surface measurement threshold should be reduced. In Figures 3 and 5, the threshold has been reduced to 4° (vertical dotted lines). More kyphosis and lordosis changes are identified. However, a larger number of true unchanged curves will be incorrectly identified as modified.

This approach could then be used to decrease patient irradiation without the loss of all pertinent information regarding sagittal curvatures. This information could be very important because the scoliosis deformation is three-dimensional in nature, and the literature reveals a relationship between Cobb angle variation and sagittal modification (15,23). For example, Figure 6A-B shows two different patients with similar spines in the frontal plane, but their respective sagittal curves show obvious differences (Fig. 6C-D). Within this context, the evaluation and follow-up of sagittal curve evolution could be essential to understanding the pathology evolution. Orthopaedic (1,2,11,13,20,21) and surgical (2,4,8) treatments usually stop frontal curve progression but could also affect the sagittal curvatures of the spine. Sagittal configuration also seems to be correlated with back pain and pulmonary function in adults with idiopathic scoliosis (10,18).

CONCLUSION

The advantage of the approach presented in this study rests on its noninvasive nature and its integration in a complete postural evaluation (6). This approach was not developed to replace radiographs, from which much more information could be drawn. Although the estimate at follow-up is very good for kyphosis and lordosis, the detection of a significant change is less accurate, and this should be taken into consideration when establishing the objectives of the evaluation. The large mobility of the lumbar spine in the sagittal plane seems to induce more variability in the lordosis estimation. However, the analysis of the surface of the back could also reflect changes that the radiologic measurement using the Cobb technique could not reveal (19). The proposed strategy could be used during follow-up to reduce patient irradiation.

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REFERENCES

1. Asher M, De Smet A, Whitney W, et al. Changes in spinal alignment resulting from spinal deformity orthoses in patients with idiopathic scoliosis. *Orthop Trans* 1987;11:105–6.
2. Bridwell KH. Normalization of the coronal and sagittal profile in idiopathic scoliosis: options of treatment. *J Orthop Sci* 1998;3:125–34.
3. Carman DL, Browne RH, Birch JG. Measurement of scoliosis and kyphosis radiographs. *J Bone Joint Surg Am* 1990;72:328–333.
4. D'Andrea LP, Betz RR, Lenke LG, et al. The effect of continued posterior spinal growth on sagittal contour in patients treated by anterior instrumentation for idiopathic scoliosis. *Spine* 2000;25:813–8.
5. D'Osualdo F, Schierano S, Iannis M. Validation of clinical measurement of kyphosis with a simple instrument, the Arcometer. *Spine* 1997;22:408–413.
6. De la Huerta F, Leroux MA, Zabjek KF, et al. Évaluation stéréovidéographique de la géométrie posturale du sujet sain et scoliotique. *Ann Chir* 1998;52:776–83.
7. Deacon P, Flood BM, Dickson RA. Idiopathic scoliosis in three dimensions. A radiographic and morphometric analysis. *J Bone Joint Surg Br* 1984;66:509–12.
8. Deckey JE, Court C, Bradford DS. Loss of sagittal plane correction after removal of spinal implants. *Spine* 2000;25:2453–60.
9. Goldberg MS, Poitras B, Mayo NE, et al. Observer variation in assessing spinal curvature and skeletal development in adolescent idiopathic scoliosis. *Spine* 1988;13:1371–7.
10. Jackson RP, Simmons EH, Stripinis D. Coronal and sagittal plane spinal deformities correlating with back pain and pulmonary function in adult idiopathic scoliosis. *Spine* 1989;14:1391–7.
11. Labele H, Dansereau J, Bellefleur C, Poitras B. Three-dimensional effect of the Boston brace on the thoracic spine and rib cage. *Spine* 1996;21:59–64.
12. Leroux MA, Zabjek K, Simard G, et al. A non-invasive anthropometric technique for measuring kyphosis and lordosis: an application for idiopathic scoliosis. *Spine* 2000;25:1689–94.
13. Lindh M. The effect of sagittal curve changes on brace correction of idiopathic scoliosis. *Spine* 1980;5:26–36.
14. Mellin G. Measurement of thoracolumbar posture and mobility with a Myrin inclinometer. *Spine* 1986;11:759–62.
15. Ohlen G, Aaro S, Bylund P. The sagittal configuration and mobility of the spine in idiopathic scoliosis. *Spine* 1988;13:413–6.
16. Öhlén G, Spangfort E, Tingvall C. Measurement of spinal sagittal configuration and mobility with Debrunner's Kyphometer. *Spine* 1989;14:580–3.

17. Stokes IA, Bigalow LC, Moreland MS. Three-dimensional spinal curvature in idiopathic scoliosis. *J Orthop Res* 1987;5:102–13.
18. Upadhyay SS, Mullaji AB, Luk KD, Leong JC. Relation of spinal and thoracic cage deformities and their flexibilities with altered pulmonary functions in adolescent idiopathic scoliosis. *Spine* 1995;20:2415–20.
19. Voutsinas SA, MacEwen GD. Sagittal profiles of the spine. *Clin Orthop* 1986;210:235–42.
20. Willers U, Normelli H, Aaro S, et al. Long-term results of Boston brace treatment on vertebral rotation in idiopathic scoliosis. *Spine* 1993;18:432–5.
21. Willner S. Effect of the Boston thoracic brace on the frontal and sagittal curves of the spine. *Acta Orthop Scand* 1984;55:457–60.
22. Willner S. Spinal pantograph: a non-invasive technique for describing kyphosis and lordosis in the thoraco-lumbar spine. *Acta Orthop Scand* 1981;52:525–9.
23. Xiong B, Sevastik J, Hedlund R, Sevastik B. Sagittal configuration of the spine and growth of the posterior elements in early scoliosis. *J Orthop Res* 1994;12:113–8.