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J. Griffet
M. A. Leroux
J. Badeaux
C. Coillard
K. F. Zabjek
C. H. Rivard

Relationship between gibbosity and Cobb angle during treatment of idiopathic scoliosis with the SpineCor brace

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J. Griffet (✉)
Department of Child Surgery,
Faculty of Medicine,
University of Nice-Sophia-Antipolis.
Hôpital de l'Archet
151 Route de Saint Antoine de Ginestière,
BP3079, 06202 Nice cedex 3, France
e-mail: griffet.j@chu-nice.fr,
Tel.: +33-4-92036471

M. A. Leroux · J. Badeaux · C. Coillard
K. F. Zabjek · C. H. Rivard
Department of Surgery,
Faculty of Medicine, Montreal University,
Research Centre, Sainte-Justine Hospital,
Montreal, Quebec, Canada

Abstract The objective of this study was to quantify the relationship between gibbosity and spinal deformation expressed by the angle of Cobb before and during treatment with a brace for different classes of idiopathic scoliosis patients. As part of the standard treatment with the Dynamic Corrective Brace (SpineCor), 89 idiopathic scoliosis patients underwent an initial radiological examination and gibbosity measurement with a scoliometer wearing and not wearing the brace. The 89 patients were classified in relation to the apex of the scoliosis curves: thoracic (n = 29); thoracolumbar (n = 40); lumbar (n = 7) and double (n = 13). With the dynamic corrective brace, the patients showed a mean decrease of 8.3° for the major Cobb angle, and a mean decrease of 2.3° for their gibbosity. There was a significant positive relationship between gibbosity and Cobb angle with and without the brace for the thoracic and thoracolumbar curves. A linear regression analysis identified a small mean estimation error for the thoracic curves (7.4° no-brace; 2.7° with brace) and thoracolumbar curves (5.2° no-brace; 5.3° with brace), indicating a predictive potential of the scoliometer. The measure of gibbosity with the scoliometer provides a fairly reliable estimation of Cobb angle at the initial clinical examination of a scoliosis patient. However, when initial Cobb angle and gibbosity are considered, the measure of gibbosity when wearing a brace provides the clinician with a highly reliable estimation of the Cobb angle while in a brace. This relationship also exists for the follow-up with a brace, permitting a judgement of the patient's evolution under the treatment with SpineCor.

Key words Scoliosis · Prominence · Cobb angle · Brace

Introduction

Idiopathic scoliosis is a multifaceted pathology that progresses mainly during periods of growth [6, 7, 9,22], manifesting itself in the form of a lateral curvature of the spine [23], vertebral deformations [3] rotation [17], and postural abnormalities [5]. The diagnosis is based on the association of a gibbosity, observed during the clinical examination and the presence of a spinal curvature measured on a frontal radiograph using the Cobb technique [4]. Since scoliosis is three-dimensional in nature there is also an impact on the impression of the spine in the sagittal plane through a modification of kyphosis and lordosis [12]. The progressive potential of a specific scoliosis is often difficult to estimate [10, 11,18], and is largely dependent upon frequent radiological evaluations (4- to 6-month intervals). The non-invasive nature and the reliability of the gibbosity measurement has lead to its utilisation in screening programs as a means of detection [1, 2,19], and as a major criterion utilised during the clinical examination of scoliosis patients. The close relationship between gibbosity and spinal curvature was identified by Korovessis and Stamatakis [13], who presented a significant regression between gibbosity and the amplitude of the Cobb angle. This relationship is specific to the thoracic and the lumbar levels. However, in their study, the group of patients did not seem to be representative of the scoliosis patient population, with subject recruitment limited to patients that presented a gibbosity greater than 7°. As most idiopathic scoliosis cases have an initial identified spinal curvature lower than 30°, a cut off of 7° may have excluded several scoliosis patients from the study [2]. These methodological choices could limit the use of this approach for the screening of adolescent populations.

Since the measurement of gibbosity is often used, it would be worthwhile to define a quantitative relationship between this parameter and the geometrical shape of the spine. If there is a strong relationship between the gibbosity and the Cobb angle, and if this relation persists or strengthens during orthopedic treatment, the therapeutic approach could be monitored with a limited need for invasive radiological evaluations. Through the subdivision of the patients into classes based on the location of the apex of the spinal curve [18], the quality and specificity of the relationship could also be improved upon. The objective of this study was to quantify the relationship between the gibbosity and the spinal deformation before and during treatment with a brace for different classes of idiopathic scoliosis patients.

Materials and methods

From 15 November 1994 to 31 December 1998, 123 patients were treated for idiopathic scoliosis at the Brace Clinic of the Sainte-Justine Hospital of Montreal. From this group, 89 complete files with an initial evaluation prior to any idiopathic scoliosis treatment were identified. It comprised 77 girls and 12 boys, aged from 5.5 to 17.2 years old (mean: 12.2 years old) at the beginning of the treatment. The characteristics of these patients are presented in Table 1. They are classified in relation to the apex of the scoliosis curvatures: thoracic, apex between T7 and T10 (n = 29); thoracolumbar, apex between T11 and L1 (n = 40); lumbar, apex from L2 to L4 (n = 7); and double, who presented two curves of similar magnitude (n = 13). within this group, ten major thoracic curves showed a minor lumbar curve, and one major lumbar and ten thoracolumbar showed a minor thoracic component.

All these patients underwent complete clinical and radiological examinations, showing risk of progression, before bracing with the Dynamic Corrective Brace (SpineCor). The examinations, performed by the same orthopedic surgeon, were repeated during the treatment for a mean follow-up of 12.2 months (SD: 1.4 months). The initial evaluation of the Cobb angle and gibbosity was performed without brace or orthopedic shoe lift, to record the initial state of the patient. The second set of measurements was performed during the treatment, with the patients wearing the brace. In addition, 27 patients (21 thoracolumbar, 4 lumbar and 2 double curves) were also fitted with a shoe lift as a complement to the brace treatment. During this study, all patients were compliant with the treatment. At the present time, 38 patients are still being treated with the brace, 36 patients have been weaned, 8 patients were submitted to surgery and 7 patients refused to follow the treatment.

The gibbosity was measured using the scoliometer (Orthopaedic Systems Inc., Hayward, Calif.), with the standing subject flexing forward at the hips and back near the horizontal (Fig. 1). The greatest magnitude of the incline of the back was noted as well

Fig. 1 Measurement of gibbosity with scoliometer in patient treated by SpineCor

as the apical level, where this value was noted. The spinal deformation was measured, as proposed by Cobb [4], on a postero-anterior (PA) radiograph. Kyphosis and lordosis were measured on the lateral (Lat) radiograph between the inferior endplate of T2 and the inferior endplate of T12, and between the inferior endplates of T12 and L5 respectively.

A Student t-test on paired data was applied to compare the data collected at the initial visit to those recorded during the follow-up. The relationship between the gibbosity and the radiological parameters was defined using the Pearson correlation coefficient. The same analysis was repeated after the subdivision of the group of patients into the four subclasses (thoracic, thoracolumbar, lumbar and double). The linear regressions were also computed to quantify the predictive potential of the measured parameters to estimate the Cobb angle. The estimation error (SE) was defined as the mean of the absolute difference between the observed and predicted scores. All statistics were computed using the Statistica software for Windows (Statsoft Inc., Tulsa, Okla.).

Results

The data collected from the clinical and radiological examination are presented in Table 1 for the initial evaluation and in Table 2 for the follow-up visit. The patients showed, with the brace, a mean decrease of 8.3° (SD: 6.3°) in their major Cobb angle ($P < 0.01$) and a mean decrease of 2.3° (SD: 3.0°) in their gibbosity ($P < 0.01$).

Gibbosity and Cobb angle

Thoracic curves

At the initial visit, all patients with an apex between T7 and T10 showed a mean thoracic gibbosity of 8.6° (SD:

Table 1 Initial patient characteristics (*Th* thoracic, *TL* thoracolumbar, *L* lumbar, *K* kyphosis, *LO* lordosis)

Class	Sex	Age (years) Mean (SD)	Gibbosity (°) Mean (SD)	Vertebral level	Cobb (°) Mean (SD)	K (°) Mean (SD)	LO (°) Mean (SD)
Th (*n* = 29)	5 M/24 F	11.8 (2.7)	10.8 (3.5)	T5-T10	34.5 (11.2)	27.1 (12.8)	52.7 (14.3)
TL (*n* = 40)	6 M/34 F	12.7 (1.9)	5.9 (3.8)	T10-L2	24.8 (7.6)	31.5 (12.1)	51.7 (11.8)
Double (*n* = 13)	1 M/12 F	12.5 (2.2)	Th: 7.3 (3.1) L: 5.6 (2.3)	T5-T9 T12-L3	Th: 27.4 (9.6) L: 28.9 (10.9)	31.5 (12.1)	47.8 (8.4)
L (*n* = 7)	7 F	12.6 (1.2)	6.0 (2.1)	L1-L3	24.9 (7.5)	38.3 (11.2)	66.3 (17.9)

Table 2 Characteristics of the patient with the brace (WB) and the amplitude of the induced changes (C), for a mean follow-up of 12.2 months. A shoe lift was used to complement the treatment in 27 patients

Class	Gibbosity (°) Mean (SD)		Cobb (°) Mean (SD)		Kyphosis(°) Mean (SD)		LO (°) Mean (SD)	
	WB	C	WB	C	WB	C	WB	C
Th	7.0 (3.2)	–3.4* (2.8)	22.6 (9.1)	–9.2* (5.2)	26.4 (10.1)	1.5 (8.7)	45.0* (13.3)	–4.2 (6.4)
TL	3.3 (2.3)	–2.5* (3.0)	14.9 (10.4)	–10.0* (6.9)	34.1 (10.9)	2.2 (8.6)	52.0 (10.6)	0.0 (9.8)
Double								
Th	5.1 (3.1)	–0.9 (2.8)	19.0 (10.7)	–6.0* (6.0)	29.9 (10.0)	–2.0 (9.4)	40.5 (12.1)	–5.9 (7.3)
L	4.1 (3.5)	–1.3 (2.2)	17.9 (12.9)	–9.3* (5.8)				
L	4.6 (3.3)	–1.4 (2.5)	16.1 (11.6)	–8.7* (5.9)	33.7 (13.8)	–2.8 (11.3)	58.7 (17.6)	–4.0 (5.6)

*$P < 0.05$, significantly different from the initial condition

4.4°). The maximum incline was measured at ±1.0 vertebral level (SD: 1.0 level) of the apex of the scoliosis curve. The correlation between the gibbosity and the Cobb angle was significant (r = 0.59). At the thoracic level, a larger gibbosity will be associated with a larger Cobb angle (Fig. 2 A). The two parameters were linked together using the following regression:

Cobb angle = 14.8 + (1.68*Gibbosity)

The mean estimation error is 7.4° (SD: 6.3°). For each group showing a thoracic curve, the correlation coefficients are: major thoracic only (n = 29), r = 0.45; thoracic component of the double curves (n = 13), r = 0.16; minor thoracic curves noted for other patients (n = 10), r = 0.44.

When evaluated during the treatment, the thoracic curves, minor and major, showed a mean decrease of 7.4° (SD: 6.0°, P < 0.01) when compared to the values measured at the initial visit. The gibbosity of these patients

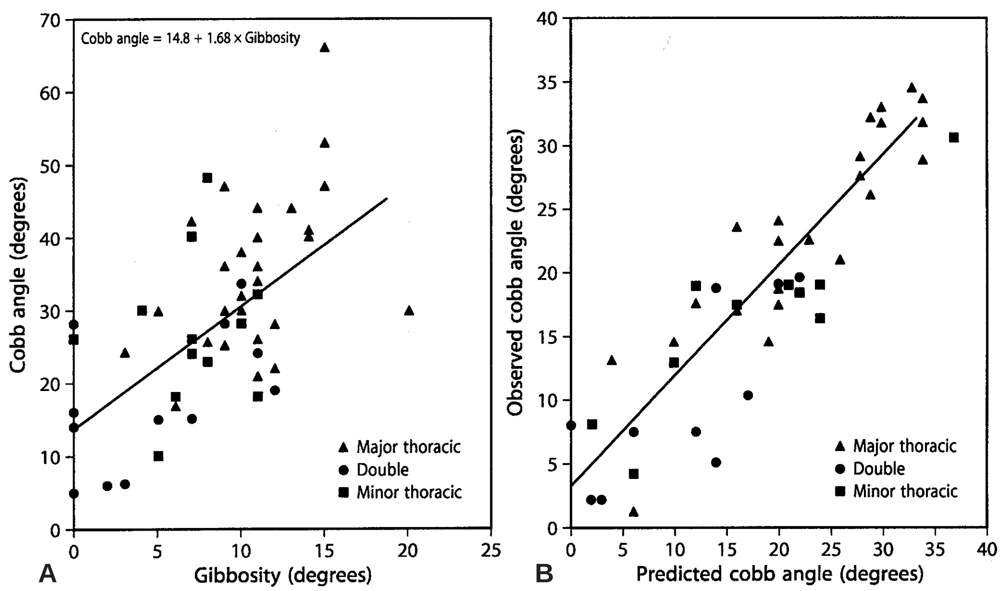

Fig. 2 A, B Thoracic curves. **A** Correlation between gibbosity and Cobb angle. **B** Relationship between predicted and observed Cobb angle

also decreased by 2.4° (SD: 3.2°, $P < 0.01$). The gibbosity decrease was 3.4° (SD: 2.8°) for the major thoracic group alone. The correlation coefficient calculated with the brace also showed a strong relationship between the gibbosity and the Cobb angle, $r = 0.67$, for all thoracic curves. However, no relationship was found, $r = 0.20$, between the change in gibbosity and the change in Cobb angle between the two visits. On the other hand, it is possible to estimate the Cobb angle amplitude with the brace without the need of a radiograph, using the initial gibbosity and Cobb angle and the measurement of the gibbosity in the brace. The following regression, $r = 0.89$, was associated with an estimation error of 3.7° (SD: 2.6°) when all thoracic curves were grouped together:

Cobb with brace = –1.4 + (0.01 × initial gibbosity) + 0.59 × initial Cobb + (0.88 × gibbosity in brace)

The relationship between the measured and predicted Cobb angle is presented in Fig. 2 B. If only the major right thoracic curves are considered, the coefficient of the new regression increases to 0.91, and the estimation error decreases to 2.7° (SD: 2.0°).

Thoracolumbar curves

At the initial visit, the patients with a curve apex between T11 and L1 showed a mean gibbosity of 6.3° (SD: 3.9°). The maximum incline was measured at ±1.0 vertebral level (SD: 1.1 level) of the apex of the scoliosis curve. The correlation between the gibbosity and the Cobb angle, $r = 0.47$, is significant,. At the thoracolumbar level, a larger gibbosity will be associated with a larger Cobb angle (Fig. 3 A). The two parameters were linked using the following regression:

Cobb angle = 19.0 + (0.92*Gibbosity)

The mean estimation error is 5.2° (SD: 4.0°). For each group showing a thoracolumbar curve, the correlation coefficients were: right thoracolumbar ($n = 11$), $r = 0.35$; left thoracolumbar ($n = 29$), $r = 0$.

When evaluated during the treatment, the thoracolumbar curves, right and left, showed a mean decrease of 10.0° (SD: 6.9°, $P < 0.01$), when compared to the values measured at the initial visit. The gibbosity of these patients also showed a decrease of 2.4° (SD: 3.0°, $P < 0.01$). The correlation coefficient calculated with the brace also supported the relationship between the gibbosity and the Cobb angle, $r = 0.42$. However, no relationship was found, $r = –0.03$, between the change in gibbosity and the change in Cobb angle between the two visits. As with the thoracic curves, it is possible to estimate the Cobb angle amplitude with the brace without the need of a radiograph using the following regression:

Cobb with brace = –8.8 + (0.4 × initial gibbosity) + (0.9 × initial Cobb) + –0.7 × gibbosity with brace)

The relationship between the measured and predicted Cobb angle is presented in Fig. 3. The coefficient is $r = 0.73$ and the estimation error is 5.3° (SD: 5.0°). However, if only left thoracolumbar curves are considered, the coefficient increases to $r = 0.79$, and the estimation error is smaller (4.2°).

Lumbar curves

At the initial visit, the patients with a curve apex between L2 and L4 showed a mean lumbar gibbosity of 5.1° (SD: 2.6°). The maximum incline was measured at ±0.6 verte-

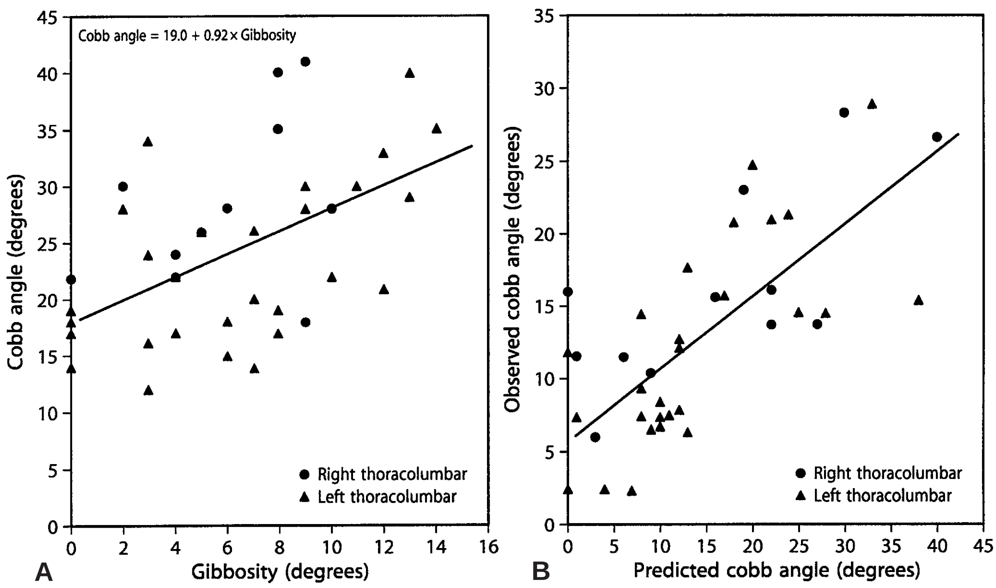

Fig. 3 A, B Thoracolumbar curves. **A** Correlation between gibbosity and Cobb angle. **B** Relationship between predicted and observed Cobb angle

bral level (SD: 0.6 level) of the apex of the scoliosis curve. The correlation between the gibbosity and the Cobb angle is not significant, at $r = 0.20$. At the lumbar level, there is no relationship between gibbosity and Cobb angle. For each group showing a lumbar curve, the correlation coefficients are: major lumbar only ($n = 7$), $r = 0.35$; lumbar component of the double curves ($n = 13$), $r = -0.22$; minor lumbar curves noted for other patients ($n = 7$), $r = 0.41$.

When evaluated during the treatment, the lumbar curves, minor and major, show a mean decrease of 7.2° (SD: 5.8°, $P < 0.01$) when compared to the Cobb values measured at the initial visit. The gibbosity of these patients also showed a decrease, of 1.9° (SD: 2.6°, $P < 0.01$). The correlation coefficient calculated with the brace showed a weak relationship between the gibbosity and the Cobb angle, of $r = 0.28$ for all lumbar curves. No relationship was found, $r = 0.22$, between the change in gibbosity and the change in Cobb angle between the two visits. However, it is possible to estimate the Cobb angle amplitude with the brace without the need of a radiograph using the following regression:

$$\text{Cobb with brace} = -3.4 + (-1.3 \times \text{initial gibbosity}) + (0.8 \times \text{initial Cobb}) + (1.3 \times \text{gibbosity with brace})$$

The regression coefficient $r = 0.89$ is accompanied by an estimation error of 4.8° (SD: 4.7°). The results are similar for curves with and those without minor lumbar curvatures.

Gibbosity and sagittal curves

At the initial visit, measures of kyphosis and lordosis were very similar across classes. There was no link between gibbosity and kyphosis and lordosis, with correlation coefficients of $r = -0.04$ and $r = 0.20$ respectively. There were no significant differences in kyphosis measurements between the two visits. Lordosis was significantly reduced when wearing the brace for the major thoracic group. The mean difference is 7.7° (SD: 6.4°). If all thoracic curves are grouped together, the same phenomenon is observed: a significant decrease of the lordosis curvature following bracing (mean 4.6°, SD: 8.5°).

Discussion

This study involved 89 idiopathic scoliosis patients judged as having an evolutive potential, who had not received prior treatment for their scoliosis. These patients were evaluated without the brace at their initial visit, prior to being fitted with the dynamic corrective brace SpineCor (Biorthex Inc., Montreal, Canada), and again at the end of treatment with the brace. The goal of this study was to highlight the relationship between the amplitude of the spinal deformation and that of gibbosity prior to and during treatment. The gibbosity is the clinical criterion that is most often utilised to evaluate the amplitude of scoliosis. Although the reproducibility of the measurement has been deemed acceptable by numerous authors [1, 2, 14,21], the conclusions drawn regarding this measure and the angle of Cobb seem contradictory [1, 2, 10, 11,19]. These disparities are probably related to the fact that gibbosity is measured on the surface of the back, and it is difficult to attribute to a specific internal origin.

It is generally accepted that the scoliometer measures an asymmetry of the trunk or an inclination of the trunk in a forward bending position [1, 14,20]. The specific location of the spinal deformation could be the origin of specific morphological characteristics that translate differently during the measure of gibbosity. The results of Korovessis and Stamatakis [13] demonstrated that the relationship between gibbosity and the Cobb angle seems to be different at the thoracic level in comparison to the lumbar level. The results presented in the present study also support this hypothesis. In effect, a relationship seems to exist between the gibbosity and the angle of Cobb for thoracic curves ($r = 0.60$) and thoracolumbar curves ($r = 0.47$). These correlations are similar to those reported by Duval-Beaupère [10] between the gibbosity and the supine Cobb angle. Pearsall et al. [16] found the same correlation of 0.59 between the gibbosity measured with the scoliometer and the angle of Cobb for thoracic curves. The relationship defined in this study seems different for the two classes of patients, since the parameters of the linear regression unifying the gibbosity and the angle of Cobb are different, the intercept being 14.8 and 19.0, and the slope being 1.68 and 0.92 respectively. With the intercept not being zero, it is possible that even with no gibbosity reading, a scoliotic curve may exist. These equations are also slightly different to those presented by Korovessis and Stamatakis [13], who grouped together the thoracic and the thoracolumbar curves, with a similar error of estimation of close to 6°.

However, since the location of the maximal gibbosity is almost at the same level as the apex of the curve, it is possible that the location of the spinal curvature induced different deformations. This could be related to the mobility of the spinal zone affected and the presence/absence of ribs. The difference in the slope of the regression supports this point. An increase of 1° of gibbosity is related to a smaller increase in the Cobb angle for thoracolumbar curvatures, which benefit from more mobility [23] prior to affecting the geometry of the thorax, than for thoracic curvatures (0.92° vs 1.68°). In a single class, the relationship between gibbosity and Cobb angle could therefore be affected by the exact location of the apex and the residual mobility of the spine in addition to other factors such age and sex.

For lumbar curves, the relationship identified between the angle of Cobb and the gibbosity is for the most part weak (r = 0.20), and contrary to that identified by Korovessis and Stamatakis [13] for 97 patients. It is possible that, in the present study, the sample size of this class was too small (27 patients) to obtain a similar trend.

The results obtained during treatment with the dynamic corrective brace SpineCor are similar to those obtained at the initial non-treated evaluation. During treatment, the patients demonstrated a decrease in the spinal deformation (8.3°) and also a decrease in the gibbosity (2.3°). The correlation between the gibbosity and the angle of Cobb during treatment with the brace was 0.67 for the thoracic region, 0.42 for the thoracolumbar region and 0.28 for the lumbar region. However, this relationship between the change in the gibbosity and the change in the Cobb angle is very weak for all the groups. This result could be explained by a weak mean change in relation to the measurement error associated with both parameters. In effect, an error of 1.96° could be encountered with one evaluator using the scoliometer [13], and the error generally accepted using the Cobb angle is close to 5° [8]. The coefficient of correlation measured on small scales does not adequately reflect the observed phenomenon.

It is possible to get a better estimate of the Cobb angle in the brace, without having to rely on the radiographic measurement, by measuring the gibbosity and the angle of Cobb made on the initial visit and the measure of gibbosity made with the brace. The mean correspondence between the predicted angles of Cobb and measured angles varies between 3.7° and 5.3° across the three classes of patient. Therefore the multiple regression calculated is very sensitive to the three types of curves studied, supporting a different expression of the spinal deformation of the thorax as a function of its location.

This study revealed that the expression of the gibbosity does not correspond to a one-to-one relationship with the Cobb angle. Vertebral rotation, the presence of the thoracic cage and its eventual deformation by scoliosis, accompanied by late thoracic growth are all elements to be taken into consideration. A relationship seems to exist between gibbosity and the angle of Cobb that may permit an improvement to the clinical approach chosen, in particular for thoracic and thoracolumbar curves. The change in the amplitude of the gibbosity makes it possible to predict an aggravation of the curve, since 1° of gibbosity corresponds to a 1.7° increase inCobb angle for thoracic, and 1° increase for thoracolumbar curves. It seems equally possible to verify the beneficial action of the dynamic corrective brace (SpineCor), since the coefficient of regression to predict the Cobb angle from the scoliometer is 0.89 for thoracic (0.91 for the right thoracic) and 0.73 for thoracolumbar curves. These regressions are pertinent to thoracic and thoracolumbar curves, as they correspond to an aggravation of greater than 5° of Cobb angle. On the other hand, this correlation can not be utilised for lumbar curves. The regression relating the initial angle of Cobb, the gibbosity before the dynamic corrective brace, and that with the dynamic corrective brace permits an estimation of the angle of Cobb with the brace and also a rapid evaluation, without complementary radiographs, of the efficiency of the brace.

The correlation between the amplitude of the gibbosity and sagittal curves was very weak both before and after treatment. This corresponds with the lack of a relationship previously found between Cobb angle, kyphosis and lordosis [15]. As scoliosis is a three-dimensional pathology affecting vertebral rotation, and, in consequence, thoracic rotation, the implications for the sagittal plane are not clear. Kyphosis and lordosis did not change in a significant manner, with changes in the Cobb angle and gibbosity over the period of treatment, with the exception of the thoracic group where lordosis decreased by approximately 8°. It is very important to note that, despite this decrease, the amplitude of the lordosis with the brace stayed well within the reported norms [12].

Conclusion

After the diagnosis of idiopathic scoliosis using clinical and radiological evaluations, the measure of gibbosity with the scoliometer provides only a fairly reliable estimation of Cobb angle prior to the treatment. A similar relationship also exists during the follow-up with the SpineCor brace. The gibbosity cannot be utilised as the only criterion by which to judge the prognosis of idiopathic scoliosis. However, when the measure of gibbosity in the brace is used in combination with the initial Cobb angle and gibbosity, it is possible to limit the necessity of a radiograph at each visit. In this situation, the gibbosity provides more information regarding the thoracic than the thoracolumbar region. However, only by taking into consideration a number of defining criteria, as demonstrated by Duval-Beaupère [11], can methods of prognosis be improved.

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