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ORIGINAL ARTICLE

Factors affecting curve flexibility in skeletally immature and mature idiopathic scoliosis

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Abstract
Background The determination of factors affecting curve flexibility is important in idiopathic scoliosis patients with regard to the Risser sign. The objective of this retrospective study was to identify factors affecting curve flexibility in patients with skeletally immature and mature idiopathic scoliosis.
Methods The records of all patients with idiopathic scoliosis who received surgical treatment from July 2001 to August 2008 at our hospital were screened. The Risser sign was used to separate the patients into a skeletally mature group (Risser grade = 5) and skeletally immature group (Risser grade < 5). Data recorded and compared were flexibility (%), bending angle (°), apical vertebral rotation (°), Cobb angle (°), curve location, prior use of brace treatment, and number of vertebrae in the curve.
Results The study cohort consisted of 217 patients (34 males, 183 females) in the Risser grade < 5 group and 124 (21 males, 103 females) in the Risser grade = 5 group. Multiple linear regression analysis revealed that the Cobb angle and the curve location significantly affected curve flexibility in the Risser grade < 5 group, whereas in the Risser grade = 5 group, Cobb angle and age significantly affected flexibility.
Conclusions Cobb angle and curve location influence main curve flexibility in skeletally immature adolescent idiopathic scoliosis, and Cobb angle and age influence curve flexibility in skeletally mature adult scoliosis. Measurement of these values may aid in the evaluation of treatment options and preoperative planning.

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Introduction

The estimation of curve flexibility in idiopathic scoliosis patients is important for determining structural curves, selecting the segment length for fusion, defining the safe range of correction, determining the most appropriate surgical procedure, and estimating the results of correction [1]. There are a number of methods for assessing flexibility, such as supine bending, push-prone, and traction under general anesthesia radiographs; each method has advantages and disadvantages [1, 2].

Although many methods for assessing flexibility exist, it is not clear what factors affect flexibility, and few studies have addressed this subject. Some researchers have reported flexibility to be related to Cobb angle, age, and curve location [3, 4]. Marks et al. [5] studied 449 female and 98 male idiopathic scoliosis patients in a multicenter study and found preoperative flexibility to be less in male than in female patients. However, the average age of the male patients was significantly higher than that of the female patients in their study. Therefore, it is unclear whether the lower flexibility in males was caused by a difference in gender or a difference in age. In addition, the impact of other factors—such as degree of apical vertebral rotation, number of vertebrae in the curve, and brace treatment—on curve flexibility is not yet clear.

Adult scoliosis, defined as any curvature of the spine of >10° in a skeletally mature individual, has different curve characteristics and requires different treatment than adolescent scoliosis. In general, the spine is stiffer in adult scoliosis than in adolescent scoliosis; however, it is not clear what factors cause this difference [6].

In some areas, patients with scoliosis have to wait a significant amount of time before they are able to obtain corrective surgery [4]. In addition, patients may only have anteroposterior and lateral radiographs of the whole spine in an outpatient clinic; radiographic assessment of curve flexibility is not performed immediately preoperatively, though flexibility is an important factor affecting surgical treatment.

Information regarding the factors affecting flexibility would assist in the advanced planning of surgical management and when counseling patients regarding outcomes. Also, quantitative analysis of the change in flexibility with age would be helpful for estimating the effect of waiting time on the outcome of treatment. Moreover, studies of how factors such as age and Cobb angle affect flexibility in adolescent and adult scoliosis may provide further understanding of the differences between these two types of scoliosis, and scientific evidence that would allow the identification of the proper time and type of surgical treatment. The aim of this retrospective study was to compare the relationships of a number of factors with flexibility in adolescent and adult scoliosis patients, using Risser grade < 5 or =5 to divide the patients, in order to determine which factors have significant and independent effects on flexibility, and how their influence differs between the two groups.

Patients and methods

In this retrospective case review, the records of all patients with idiopathic scoliosis who attended our hospital and received surgical treatment from July 2001 to August 2008 were screened. Criteria for inclusion in the study were the following: (1) Cobb angle >10° measured from standing anteroposterior radiographs, (2) a medical history excluding the possibility that scoliosis was caused by other diseases, (3) availability of physical examination and reports on spinal magnetic resonance imaging (MRI), which were used to confirm the diagnosis of idiopathic scoliosis and exclude patients with neuromuscular scoliosis, and (4) a diagnosis of idiopathic scoliosis made by three doctors independently. Patients with incomplete radiographs or a history of previous spinal surgery were excluded. The Risser sign was used to divide the patients into two groups: patients with Risser grade = 5 and patients with Risser grade < 5. The Risser sign was used to divide the patients because a clear definition of adult scoliosis is when scoliosis occurs after skeletal maturity, which is when the Risser grade = 5. The study was approved by the Institutional Ethical Committee.

Bending radiographs, including standing anteroposterior radiographs of the whole spine and supine left and right lateral bending radiographs, were used to evaluate curve flexibility. All radiographs were taken 1 week before surgery by a single radiologist (ZQC) who had more than 5 years experience and was knowledgeable about the techniques used to evaluate scoliosis using standard methods. When the radiographs were taken, patients in the supine position actively bent to the left side and right side as much as possible, so that the twelfth rib touched the ipsilateral iliac apophysis. From the radiographs, curve type (thoracic, thoracolumbar/lumbar), apical vertebral rotation, the number of vertebrae contained in the curves, and the bending position were determined, and Cobb angles were measured by two physicians (ZQC and SHH). Curve type was defined according to the Lenke classification system: thoracic curve, apex between the T2–T11/T12 discs; thoracolumbar curves, apex between T12–L1; and thoracolumbar/lumbar curves, apex between the L1/L2 disc. The Cobb angle was measured and the Risser grade determined from the supine lateral bending radiographs. Flexibility was calculated by the following equation:

$$\text{flexibility}(\%) = [(\text{coronal Cobb angle} - \text{bending Cobb angle})/\text{coronal Cobb angle}] \times 100\%.$$

Apical vertebral rotation was measured according to Perdriolle's method [7].

To evaluate inter- and intraobserver differences, measurements of the Cobb angle, bending angle, flexibility, and apical vertebral rotation were initially made by the first examiner—ZQC (Ph.D. in orthopedics, a resident with 5 years of experience in scoliosis, with national certification)—and then the second examiner—SSH (Ph.D. in orthopedics, an associate professor with more than 10 years of experience in scoliosis, with national certification)—took the same measurements without knowledge of the previous results, and finally the first examiner repeated the measurements again according to the criteria established above. All measurements were recorded independently recorded.

Data recorded were flexibility (%), bending angle (°), apical vertebral rotation (°), Cobb angle (°), curve location, prior use of brace treatment, and number of vertebrae in the curve.

Statistical analysis

Continuous data were compared using the independent two-sample t test. Binary categorical variables were compared using the chi-square test. For the number of vertebrae in the curve, an ordinal categorical variable, the median, was used to compare the groups using the Mann–Whitney U test. Continuous data were displayed as mean ± standard deviation (SD), binary categorical data were represented by number (%), and ordinal categorical data were presented as median (interquartile range). The inter- and intraobserver differences in the measurements of Cobb angle, bending angle, flexibility and apical vertebral rotation were evaluated with regard to reproducibility (intraclass coefficient of correlation—ICC), with values of >0.8 being considered as excellent, and internal consistency (Cronbach's alpha), with values of >0.8 being considered indicative of good reliability. Relationships between basic characteristics and flexibility were assessed using the Pearson correlation coefficient (r, for continuous variables), the Kendall correlation coefficient (τ, for ordinal variables, the number of vertebral bodies), and the point biserial correlation coefficient (r_{pb}, for categorical variables with two levels). Linear regression analysis was performed to assess the factors that affect curve flexibility. All P values were two-sided and evaluated at the 0.05 level of significance. Statistical analyses were performed using SPSS version 15.0 statistical software (SPSS Inc., Chicago, IL, USA).

Results

Table 1 shows the results of the evaluation of intra- and interobserver reliability of Cobb angle, bending angle, flexibility, and apical vertebral rotation. It indicates that Cobb angle, bending angle, flexibility, and apical vertebral rotation each showed "excellent" intraobserver reliability (all ICC > 0.8) in both the Risser grade < 5 and Risser grade $= 5$ groups. In addition, Cronbach's alpha for each measurement was more than 0.8, which means there was internal consistency with good reliability for Cobb angle, bending angle, flexibility, and apical vertebral rotation in both groups.

Demographic and baseline characteristics of the two groups are shown in Table 2. The study cohort consisted of 217 patients (34 males, 183 females) with Risser grade < 5 and 124 (21 males, 103 females) with Risser grade $= 5$. The mean age of patients with Risser grade < 5 was 14.8 ± 1.8 years (range 10.1–18.7 years), and the mean age of patients with Risser grade $= 5$ was 28.1 ± 9.0 years (range 14.8–50.3 years). Among the patients in the Risser grade < 5 group, there were 119 Lenke type I, 17 type II, 11 type III, 4 type IV, 50 type V, and 16 type VI. A positive correlation between age and Risser sign ($\tau = 0.35$, $P < 0.001$) was found.

Significant differences between the two groups were seen in Cobb angle, apical vertebral rotation, bending angles, flexibility, and curve location (all $P < 0.05$). The patients in the Risser grade $= 5$ group had greater Cobb angles (55.1 ± 15.2° vs. 51.4 ± 9.6°), apical vertebral rotations (22.2 ± 9.5° vs. 20.0 ± 8.4°), and bending angles (32.9 ± 18.2° vs. 24.7 ± 14.1°) than the patients in the Risser grade < 5 group. The patients in the Risser grade < 5 group had a higher proportion of thoracic curves.

Table 3 presents the correlations between flexibility and curve characteristics in each group. In the Risser grade < 5 group, apical vertebral rotation ($r = -0.23$, $P = 0.001$), Cobb angle ($r = -0.42$, $P < 0.001$), the number of vertebrae in the curve ($\tau = -0.14$, $P = 0.009$), and thoracic curve location ($r_{pb} = -0.27$, $P < 0.001$) were negatively correlated with flexibility. In the Risser grade $= 5$ group, age ($r = -0.50$, $P < 0.001$), apical vertebral rotation ($r = -0.23$, $P = 0.011$) and Cobb angle ($r = -0.50$, $P < 0.001$) were negatively correlated with flexibility.

The results of the multiple linear regression analysis are shown in Table 4. In the Risser grade < 5 group, Cobb angle and curve location significantly affected flexibility. When curve location was controlled for, mean flexibility decreased by a factor of 0.74 [$\beta = -0.74$, 95% confidence interval (CI) −1.04, −0.45] for each additional Cobb angle degree. When Cobb angle was controlled for instead, thoracic scoliosis showed on average 8.92% ($\beta = -8.92$, 95%

Table 1 Results of the evaluation of intraobserver (ICC) and interobserver (Cronbach's alpha) reliability in both the Risser grade < 5 and Risser grade $= 5$ groups

	Risser grade < 5		Risser grade $= 5$	
	ICC	Cronbach's alpha	ICC	Cronbach's alpha
Cobb angle (°)	0.902	0.893	0.886	0.939
Bending angle (°)	0.939	0.900	0.960	0.969
Flexibility (°)	0.815	0.915	0.880	0.934
Apical vertebral rotation (%)	0.809	0.869	0.810	0.884

ICC intraclass coefficient of correlation

Table 2 Comparison of demographic and baseline characteristics between Risser grade < 5 and Risser grade = 5 groups

	Risser grade < 5 ($n = 217$)	Risser grade = 5 ($n = 124$)	P value
Gender, male*	34 (15.7)	21 (16.9)	0.761
Age (years)†	14.8 ± 1.8	28.1 ± 9.0	<0.001§
Cobb angle (°)†	51.4 ± 9.6	55.1 ± 15.2	0.016§
Apical vertebral rotation (°)†	20.0 ± 8.4	22.2 ± 9.5	0.029§
Bending (°)†	24.7 ± 14.1	32.9 ± 18.2	<0.001§
Flexibility (%)†	53.5 ± 20.3	42.9 ± 20.8	<0.001§
Curve location, thoracic*	149 (68.7)	67 (54.0)	0.007§
Brace treatment, yes*	37 (17.1)	22 (17.7)	0.871
Number of vertebral bodies in curve‡	6 (6, 7)	6 (6, 6)	0.868

Data are presented as mean ± standard deviation, number (%), or number (interquartile range)

P values are based on the * chi-square test, † independent two-sample t test, and ‡ Mann–Whitney U test

§ Significant difference, $P < 0.05$

Table 3 Correlations of flexibility and curve characteristics in both Risser grade < 5 and Risser grade = 5 groups

	Risser grade < 5 ($n = 217$)		Risser grade = 5 ($n = 124$)	
	Correlation coefficient	P value	Correlation coefficient	P value
Gender*	−0.01	0.954	−0.04	0.660
Age (years)†	−0.01	0.929	−0.50	<0.001§
Apical vertebral rotation (°)†	−0.23	0.001§	−0.23	0.011§
Cobb angle (°)†	−0.42	<0.001*	−0.50	<0.001*
Number of vertebral bodies in curve‡	−0.14	0.009*	−0.01	0.950
Brace treatment*	0.10	0.130	−0.02	0.833
Curve location*	−0.27	<0.001§	−0.17	0.067

* Point biserial correlation coefficient

† Pearson correlation coefficient

‡ Kendall correlation coefficient

§ Significant difference, $P < 0.05$

Table 4 Results of a multiple linear regression analysis to determine factors affecting curve flexibility in both Risser grade < 5 and Risser grade = 5 groups

	Risser grade < 5 ($n = 217$)		Risser grade = 5 ($n = 124$)	
	β (95% CI)	P value	β (95% CI)	P value
Age (years)	–		−0.84 (−1.20, −0.48)	<0.001*
Apical vertebral rotation (°)	−0.19 (−0.52, 0.15)	0.269	0.21 (−0.17, 0.60)	0.268
Cobb angle (°)	−0.74 (−1.04, −0.45)	<0.001*	−0.58 (−0.83, −0.32)	<0.001*
Number of vertebral bodies	−1.48 (−4.48, 1.52)	0.3314	–	
Curve location	−8.92 (−14.70, −3.15)	0.003*	–	

CI confidence interval, – not included in the final model

* Significant difference, $P < 0.05$

CI −14.70, −3.15) less flexibility than thoracolumbar scoliosis/lumbar scoliosis. In the Risser grade = 5 group, Cobb angle and age significantly affected flexibility. When age was controlled for, mean flexibility decreased by a factor of 0.58 ($\beta = -0.58$, 95% CI −0.83, −0.32) for each additional Cobb angle degree. When Cobb angle was controlled for, the mean flexibility decreased by a factor of 0.84 ($\beta = -0.84$, 95% CI −1.20, −0.48) for each additional year of age. Apical vertebral rotation and number of vertebrae in the curve did not statistically significantly affect flexibility in either group.

Discussion

Curve flexibility in scoliosis predicts the results of correction, determines the safe range of scoliosis correction, and is also very important for making decisions about fusion segments and the surgical approach [8, 9]. In this study, we evaluated factors affecting curve flexibility in skeletally immature (Risser grade < 5) and skeletally mature (Risser grade = 5) idiopathic scoliosis. The Risser grade < 5 and Risser grade = 5 patient groups had similar Cobb angles, number of vertebrae in the curve, and prior use of a brace, but significantly different flexibility, bending angles, apical vertebral rotation, and curve location. The results from this study showed that Cobb angle and curve location were significantly related to curve flexibility in skeletally immature idiopathic scoliosis, and that Cobb angle and age were significantly related to curve flexibility in skeletally mature idiopathic scoliosis. In the Risser grade < 5 group, curve flexibility decreased as Cobb angle increased. Flexibility also decreased in the Risser grade = 5 group as Cobb angle increased, but the reduction in flexibility was not as large. This was because the curve was relatively stiff in the Risser grade = 5 patients, so the change in Cobb angle had less effect on flexibility than in the Risser grade < 5 patients.

Deviron et al. [3] reported that for every 10° increase in curve magnitude, a 10% decrease in structural curve flexibility occurs, and for every 10-year increase in age, structural curve flexibility decreases by 5%. However, Deviron et al.'s study cannot strictly be compared to ours because they did not separate adolescent and adult data and did not include thoracic curves. Our results showed that in patients with Risser grade < 5, after the effects of Cobb angle and age were excluded, curve location did affect flexibility. There are two possible explanations for the flexibility difference between thoracic and lumbar curves: the presence of the rib cage reduces thoracic curve flexibility and/or the thoracolumbar/lumbar curve, being on a lower part of the spine than the thoracic curve, withstands a greater load, which results in a larger "collapse" effect and increases flexibility.

In the Risser grade = 5 group, the effect of curve location on flexibility was not as large as in the Risser grade < 5 group. The likely explanation is that the thoracic curve in the mature spine has already become stiff and has less potential to change than that of the lumbar curve. When the flexibility of the lumbar curve is reduced with age, the difference in flexibility between the thoracic and lumbar curve disappears.

In our study, curve flexibility in the Risser grade = 5 group decreased as age increased, whereas in the Risser grade < 5 group, flexibility did not change with age. The changes in soft tissue around the spine as well as changes in spinal structure and in physical capability that occur with age may affect curve flexibility. Our result is different from that reported by Clamp et al. [4], who found that curve flexibility in adolescents varied with age. This difference in results may be due to the fact that the mean age of Clamp et al.'s adolescent group was older than that of our adolescent group with Risser grade < 5. Also, the age range of their group was not given, so there may have been patients that would have been classified as adults based on our criteria.

There are two possible explanations for the different effect of age in the Risser grade < 5 and Risser grade = 5 groups in our study. First, an increase in spinal stiffness occurs very slowly with age, and short-term changes in flexibility are small. Therefore, the change in flexibility attributable only to age in the adolescent age group would not be large. Second, flexibility decreases very slowly in adolescents, but decreases dramatically and quickly when adulthood has been reached.

Our observation that age did not have a significant effect on flexibility in the Risser grade < 5 group suggests that it is not essential to perform surgery at the time of diagnosis. If corrective surgery has to be postponed due to factors such as long waiting lists and financial concerns, a good surgical correction can still be achieved if the Cobb angle has not increased. However, if the Cobb angle has increased as the patient has grown older, the outcome of the operation will be affected.

In our analysis, gender had no impact on flexibility; however, other researchers have reported that the spine in males is stiffer than in females [10]. Clinically, the reduced flexibility found in males results from the mixed effect of Cobb angle, age, and other factors [10]. In a study by Marks et al. [5], the flexibility of the spine in males was found to be less than that in females, but this was most likely due to the fact that the male patients were older, and was not an effect of gender.

In this study we found no significant correlation between the number of vertebrae affected by scoliosis and flexibility, which makes us question the view that a longer segment of scoliosis may be more flexible than a relatively short segment of scoliosis. Our results also indicated there was no significant correlation between brace treatment and flexibility; thus, for patients who require surgery after failed brace treatment, except for the effects of increasing of scoliosis angle due to brace treatment failure, the impact on flexibility due to brace treatment is not significant.

There are a number of ways to evaluate curve flexibility [1, 2]. We chose lateral bending radiographs for assessment because they are a widely used classic method, and the basis of the King [8], Lenke [9] and PUMC [11] classification systems. Clamp et al. [4] employed fulcrum bending radiographs to evaluate flexibility because they found that they could estimate the postoperative correction rate more accurately than with other methods. However, while fulcrum bending radiographs are good for evaluating major thoracic curves [12], they are not useful for the evaluation of upper thoracic and thoracolumbar/lumbar curves; therefore, other methods must be combined with fulcrum bending radiographs for a complete evaluation [13]. Because of the support provided by the ribs, the stretching force applied to the thoracic curve is greater than that applied to the thoracolumbar/lumbar curve during fulcrum bending radiographs, so the thoracic curve may display increased flexibility. If we had used fulcrum bending radiographs in our study, the flexibility of thoracic curves would have been artificially increased, so the results would have been misleading when compared to the curve flexibilities of different locations.

In summary, this study demonstrated that Cobb angle and curve location have significant influences on main curve flexibility in skeletally immature idiopathic scoliosis. We also confirmed the significant influence of Cobb angle and age on curve flexibility in skeletally mature idiopathic scoliosis. We believe that the measurement of these values will aid in preoperative planning and may be useful for providing helpful information to patients who are making decisions regarding nonoperative and operative treatment options.

Conflict of interest The authors declare that they have no conflict of interest regarding this work.

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