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ORIGINAL ARTICLE

Factors relating to curve progression in female patients with adolescent idiopathic scoliosis treated with a brace

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Abstract
Purpose One single factor cannot by itself predict curve progression accurately. The aim of this study is to determine multiple related factors in predicting the progression of scoliosis in girls with adolescent idiopathic scoliosis (AIS) treated with bracing.
Methods Eighty-nine female patients with AIS treated with a brace were reviewed. A series of parameters were consecutively measured and documented during the period of follow-up. Curve behavior between the first visit and final follow-up was analyzed. Several different parameters which may contribute to progression of curve were selected by a logistic regression analysis.
Results Mean age of patients at the first visit was 13.6 (10–16) years. The patients were followed for 12–72 months (mean 24.8 months). At the last visit, 21 patients (23.60 %) had curve progression more than 5°. After performing a logistic regression analysis, Risser sign less than two, the magnitude of the major curve at pre-brace greater than 35°, apical vertebral rotation beyond grade III, and the spinal length increasing larger than 20 mm in 1 year were found to be factors which predict the progression of more than 5°.
Conclusions This study suggests that Risser sign, the magnitude of the major curve at pre-brace, apical vertebral rotation, and the spinal length increasing velocity are important factors to predict progression in the girls with AIS. Risser sign cannot predict the progression of scoliosis accurately unless combined with other related parameters.

Keywords Scoliosis · Adolescent · Bracing · Progression

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Introduction

It is very important to predict the progression of adolescent idiopathic scoliosis (AIS). Until this time, there are no accurate methods to predict curve progression in AIS. Previous studies [1, 2, 14, 15, 17, 19, 20] have indicated that the risk of curve progression is correlated with factors including Cobb angle, curve pattern, menarche status, sitting heights, standing heights, Risser sign, and apical vertebral rotation. However, it is not clear to what extent they can be used in predicting the curve behavior when treated with a brace.

Noordeen and Hoppenfeld [3, 4] found that Risser sign is a critical parameter in predicting curve progression. Considering a single factor only cannot predict curve progression accurately. Therefore, the objective of this study was to measure and document a series of parameters which may contribute to progression of curve during the period of follow-up. Parameters which contribute to progression of curve were selected by a logistic regression analysis. It is possible to find a regression equation which is used to predict the probability of curve progression.

Materials and methods

The criteria for patient admission in this study include: (1) no previous history of medical treatment; (2) older than 10 years of age; (3) mild and moderate scoliosis (Cobb angle <45°); (4) no sign of degenerative disorders; (5) equal lower limbs without any anomalies.

A total of 89 consecutive female patients were selected in accordance with the above criteria. All the patients were followed up with a minimum of 1 year after treating with a brace. At the first visit, the patients were aged 10–16 years (average age, 13.6 years). Twenty cases have a thoracic curve, 45 patients have double major curve, and 24 patients have thoracolumbar or lumbar curve, Cobb angle ranged from 20° to 45°.

Patients who have a curve apex above T_7 were prescribed to wear the Milwaukee brace and those who have a curve apex below T_7 were prescribed to wear the Boston brace. After fitting the brace, a standing PA radiograph of the spine with the brace was taken to detect the correction of the primary and secondary curves. Patients were asked to wear the brace for at least 22 h per day. They were seen after 4 weeks to check adequate fitting of the brace. Related parameters and curve behavior were monitored in the outpatient clinic every 4–6 months. At every visit, standing PA radiographs of the spine without the brace were taken. Bracing was continued until the patients had reached a Risser sign of at least five and was 3 years after menarche. Treatment was considered to have failed if the curve progressed beyond 5° or if surgery was performed. There are differences in the Risser grading systems in the US and France. We used the American Risser grading systems in this study [5].

Related parameters and curve behavior were monitored in the outpatient clinic every 4–6 months. Different values were assigned as shown in Table 1.

At every visit, standing PA radiographs of the spine without the brace were taken. Cobb angle, curve pattern, menarche status, the spinal length, Risser sign, apical vertebral rotation, etc., were consecutively measured and documented.

As shown in Fig. 1, a special computer program was used to measure the spinal length. This was developed by Matlab 6.5. Using the program, we can select four vertex points from a vertebra, such as 1–4 or 5–8 (a). The program will calculate and obtain three points on the center line of the vertebra, such as A, B, and C. This step is repeated until all the vertebras from T1 to L4 are measured. By doing this, we can obtain a series of points on the center line.

Table 1 Ten risk factors potentially contributing to curve progression

Factors	Values	Assign description
Age	X_1	≤13 years = 1, >13 years = 0
Pre- or post-menarche	X_2	Pre-menarche = 1, post-menarche = 0
Types of scoliosis	X_3	Thoracic curve = 1, double major curve = 2,thoracolumbar or lumbar curve = 3
Cobb angle of primary curve	X_4	≥35° = 1, <35° = 0
Risser sign	X_5	≤2 = 1, >2 = 0
Increasing velocity of standing height (mm/year)	X_6	≥30 = 1, <30 = 0
Increasing velocity of sitting height (mm/year)	X_7	≥20 = 1, <20 = 0
Magnitude of apical vertebral rotation	X_8	≥III = 1, <III = 0
Curve patterns	X_9	Left = 1, right = 0
The spinal length increasing velocity (mm/year)	X_{10}	≥20 = 1, <20 = 0

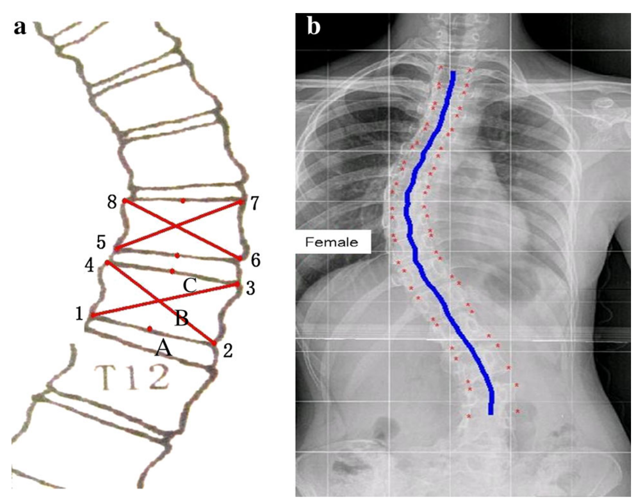

Fig. 1 The method used to calculate the spinal length. **a** A special program used to measure the spinal length was developed by Matlab 6.5. Using the program, we can select four vertex points from a vertebra, such as *1–4* or *5–8*, then the program can calculate and obtain three points on the center line of the vertebra, such as *A*, *B*, and *C*. This step is repeated until all the vertebras are measured. **b** By doing this, we can obtain a series of points on the *center line*. Based on these points, a spline interpolation algorithm was used to obtain smooth *center line*. The spinal length can then be calculated from these interpolated points

Based on these points, a spline interpolation algorithm was used to obtain the smooth center line (b). The spinal length from T1 to L4 can then be calculated from these interpolated points.

The radiographic measurements were repeated after a 2-week interval. In this study, the intra-observer error for the Cobb angle was about 2.9°. Curve progression was defined as Cobb angle increasing greater than 5°.

Statistical analysis

The results were analyzed statistically using a logistic regression analysis. Values of $P < 0.05$ were taken to represent statistical significance.

Results

The patients were followed for 12–72 months (mean 24.8 months). At the last visit, 21 patients (23.60 %) had curve progression more than 5°.

After performing a logistic regression analysis, Risser sign less than two, the magnitude of the major curve at the pre-brace greater than 35°, apical vertebral rotation beyond grade III and the spinal length increasing larger than 20 mm in 1 year were found to be factors which predict the progression of more than 5° (Table 2).

For prognostic purpose, a logistic regression analysis was performed. We constructed a mathematical equation that included the Risser sign, the magnitude of the major curve at the pre-brace, the apical vertebral rotation, and the spinal length increasing velocity were found to be factors which predicted the progression of more than 5°. The mathematical equation is as follows: $\text{logit}\ (P) = \text{Ln}(P/1-P) = -4.157 + 2.781X_8 + 2.617X_4 + 1.814X_5 + 1.808X_6$. P is equal to the estimated probability of curve progression more than 5°; logit (P) is the logit transformation of P, which is equal to Ln ($P/1-P$), Ln is the natural logarithm; X_8 is the magnitude of apical vertebral rotation; X_4 is the Cobb angle of primary curve; X_5 is the Risser sign; X_6 is the spinal length increasing velocity. The value of P is derived from the equation: $P = \exp[\text{logit}(P)]/(1 + \exp[\text{logit}(P)])$. We can use this equation to predict the probability of curve progression more than 5°.

For example, a 13-year-old girl, who has Risser sign 3, the initial Cobb angle is 48°, apical vertebral rotation I. One year later, the spinal length increasing velocity is 10 mm/year. The possibility of the curve progression is 18 %. Two years later, the spinal length increasing velocity became 30 mm/year. The possibility of the curve progression increased to 59 % (Fig. 2).

Discussion

Natural history studies have shown that the risk of curve progression increases with the magnitude of the curve and in young patients [6, 7, 23]. Nachemson et al. [8] reported that untreated female patients with curves between 25° and 35° had a progression of 66 % of curves. Several studies have confirmed that bracing changes the natural history and can limit or improve mild and moderate curves of idiopathic scoliosis effectively [7, 9, 10]. In the present study, it has been considered that treatment has failed if Cobb angles progress more than 5°, twenty-one patients (23.60 %) had curve progression more than 5°, which is a lower progression rate than untreated patients in Nachemson's study.

Bracing is the only nonsurgical measure proven to have any effect on halting the progression of mild or moderate scoliosis [7, 23]. A previous study demonstrate that bracing can be successfully used in patients who do not want to undergo operations for AIS with curves ranging between 45° and 60° [18]. The present study found the incidence of progression was 23.60 % and Cobb angle greater than 35° always progressed easily. It was similar to a previous study [15].

Previous studies found curve progression was correlated with many factors, such as chronological age, Cobb angle, curve pattern, apical vertebral rotation, Risser sign, timing of menarche, peak height velocity (PHV), and so on [16, 19–22, 24]. Karol [11] found that bracing of male

Table 2 Variables in the equation and estimated values of the corresponding parameters

Variables in the equation	Regression coefficient	Standard error	Wald χ^2	P value	$\hat{OR}$
Constant term	−4.157	0.881	22.258	0.000	0.016
*X*8 (Magnitude of apical vertebral rotation)	2.781	0.938	8.786	0.003	16.134
*X*4 (Initial Cobb angle of primary curve)	2.617	0.771	11.513	0.001	13.691
*X*5 (Risser sign)	1.814	0.762	5.669	0.017	6.137
*X*6 (the spinal length increasing velocity)	1.808	0.777	5.409	0.020	6.098

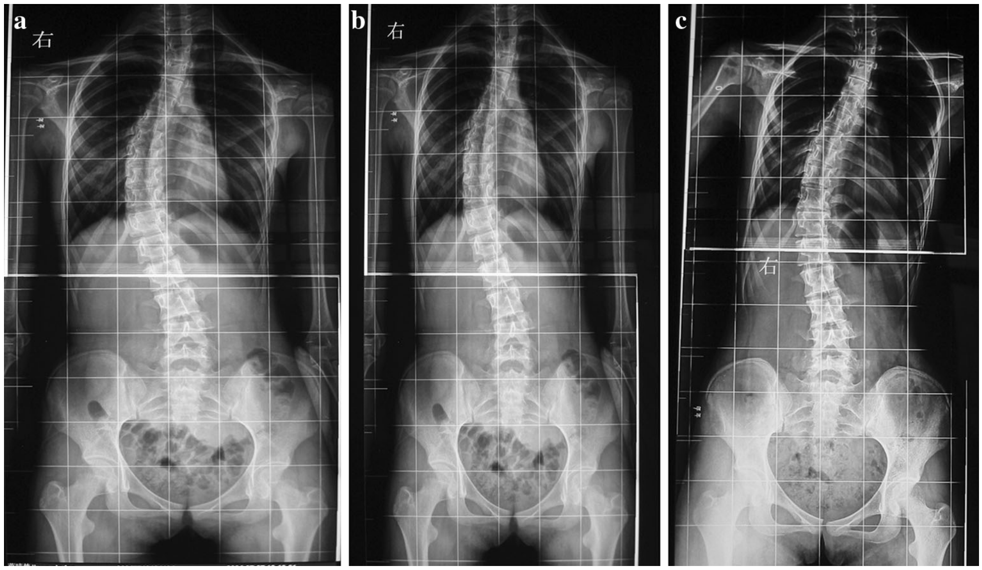

Fig. 2 **a** Posteroanterior radiograph of a 13-year-old girl with adolescent idiopathic scoliosis at presentation: Risser grade 3, primary Cobb angle 48°. **b** Posteroanterior radiograph of the girl after 1 year bracing: the spinal length increasing velocity is 10 mm/year, the possibility of the curve progression is 18 %, Cobb angle decreased to 40°, Risser grade 4. **c** Posteroanterior radiograph of the patient after 2 years brace treatment. The spinal length increasing velocity became 30 mm/year, the possibility of the curve progression increased to 59 %. The Cobb angle increased to 52°

patients with idiopathic scoliosis was ineffective. Curves measuring > or =30° are very likely to progress to surgery, especially in immature patients. The present study found the magnitude of the major curve at pre-brace greater than 35° would progress easily. Escalada et al. [12] performed a study to establish a relationship between height and angle velocities, as well as to determine if peak angle velocity (PAV) occured at the same time as PHV. They found an inverse relationship between height velocity and curve progression in the group of AIS girls with progressive curves managed with a brace. This study demonstrated that the spinal length increasing larger than 20 mm in 1 year was inclined to progress. Another study [13] found that radiological skeletal age of the wrist and digits when compared to the histologic grade of iliac crest apophysis and Risser sign could provide important information for maturity assessment in girls with AIS. In the present study, Risser sign less than two was associated with more curve progression.

The objective of this study was to determine related factors in predicting the progression of the scoliosis. Since a single factor cannot predict curve progression accurately, the present study performed a logistic regression analysis to screen risk factors. For prognostic purposes, this study constructed a mathematic equation that included the Risser sign, the magnitude of the major curve at the pre-brace, the apical vertebral rotation, and the spinal length increasing velocity.

Conclusion

In conclusion, the present study demonstrate that Risser sign, the magnitude of the major curve at the pre-brace, apical vertebral rotation, and the spinal length increasing velocity are important factors to predict progression in girls with AIS. Risser sign combined with other related parameters can predict the progression of scoliosis more accurately.

Conflict of interest None.

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