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ORIGINAL ARTICLE

Abnormal anthropometric measurements and growth pattern in male adolescent idiopathic scoliosis

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Abstract

Purpose The progression of adolescent idiopathic scoliosis is closely correlated with longitudinal growth during puberty. A decreased incidence of curve progression has been found in male patients with adolescent idiopathic scoliosis compared with female patients with the condition. This finding implies that there might be a sexual dimorphism in the pubertal growth patterns of adolescent idiopathic scoliosis patients. Abnormal pubertal growth in female adolescent idiopathic scoliosis patients has been well characterized; however, the pubertal growth patterns of male adolescent idiopathic scoliosis patients have not been reported. We conducted a cross-sectional study of anthropometric measurements to compare the growth patterns of male patients with adolescent idiopathic scoliosis with those of healthy boys during puberty and explore the difference in the pubertal growth patterns of female and male patients with adolescent idiopathic scoliosis.

Methods A total of 688 subjects were involved in the study, including 332 male adolescent idiopathic scoliosis patients and 356 age-matched healthy boys. The subjects were categorized according to their chronological ages. Their body weights, heights and arm spans were obtained using standard methods; the corrected body heights of the adolescent idiopathic scoliosis boys were determined using Bjour's equation. The inter-group differences in the anthropometric parameters were analyzed. Multivariate regression analysis was carried out in the adolescent idiopathic scoliosis patients to identify the anthropometric parameters that influence curve severity.

Results The corrected standing heights and arm spans of male adolescent idiopathic scoliosis patients were similar to those of the matched controls during puberty. However, the body weights of the adolescent idiopathic scoliosis patients who were more than 14 years old were significantly less than those of the control group. The body mass index of the adolescent idiopathic scoliosis patients between the ages of 15 and 17 were also significantly less than those of the control subjects. Moreover, a significantly higher incidence of underweight was found in adolescent idiopathic scoliosis patients (8.6%) than in the controls (3.4%). Upon multivariate regression analysis, body weight and chronological age were identified as independent predictors of curve magnitude in male adolescent idiopathic scoliosis patients. The male adolescent idiopathic scoliosis patients with variable curve patterns exhibited no significant differences in their anthropometric parameters.

Conclusions The results showed abnormal pubertal growth in the male adolescent idiopathic scoliosis patients compared with their age- and gender-matched normal controls. Despite similar longitudinal growth, the male patients with adolescent idiopathic scoliosis exhibited significantly lower body weights and a higher incidence of underweight during the later stage of puberty compared with their normal controls. These abnormalities in the pubertal growth of male patients were different from those observed in female patients with adolescent idiopathic scoliosis. Body weight could be an important parameter for further longitudinal studies on the prognostication of curve progression in adolescent idiopathic scoliosis.

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Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional spine deformity that occurs during puberty [37]. Although the etiology of AIS is unclear, the natural history of these patients has been well documented, and significant sexual dimorphism noted [25, 35]. A higher tendency toward curve progression has been reported in female AIS patients compared with male patients during puberty [4, 11, 38, 39]. The female-to-male ratio for the prevalence of AIS with mild curvature (a Cobb angle between 10° and 19°) was nearly unity (1.4:1). However, the ratio increased with the severity of the spinal deformity and was as high as 10:1 in AIS patients with Cobb angles >40° [10, 26, 38].

During puberty, it has been reported that the progression of AIS is closely related to longitudinal growth, and the fastest curve progression occurs during the peak of growth in both females [7, 8, 43] and males [16, 32, 44]. In female AIS, growth during puberty has been well characterized, and many abnormalities have been documented [9, 16, 30, 42]. Anthropometric measurements have shown that pubertal female AIS patients were taller, leaner and had longer arm spans than age-matched healthy girls [1, 17, 23, 30]. In contrast to the large number of studies focusing on female AIS, the pubertal growth of male AIS patients has not been well documented. Given the distinct differences in the natural histories of male and female AIS, we hypothesized those male AIS patients might also have abnormal growth patterns during puberty but that the pattern of abnormalities might be different from those observed in female AIS patients. Hence, this study aimed to investigate the growth patterns of boys with AIS during puberty by comparing their anthropometric parameters with those of age-and gender-matched controls and explore the differences in the pubertal growth patterns of female and male AIS patients.

Materials and methods

Study design and sampling

The clinical records of AIS patient visits between January 2003 and December 2009 were reviewed. There were 4,311 newly diagnosed AIS patients (3,613 females and 698 males). The diagnosis of AIS was based on a physical examination by senior spine doctors (Y. Q. and B. W.) and a standard standing postero-anterior X-ray film of the spine. Furthermore, for the patients with severe scoliosis (Cobb angle of major curve more than 40°) and those with mild or moderate scoliosis with an atypical curve pattern [24], a routine whole-spine magnetic resonance (MR) scan was performed. Male AIS patients meeting the following criteria were enrolled in this study: (1) a Cobb angle >10°, (2) an age ranging from 10.5 to 19.5 years, (3) no previous treatment for scoliosis, (4) a lack of neural axis abnormalities found by MR scanning and (5) a complete record of anthropometric measurements at the first clinical visit. Any subjects suffering from congenital abnormalities, skeletal dysplasia, neuromuscular diseases, endocrine diseases, connective tissue abnormalities or other types of scoliosis were excluded from the study. As a result, 332 male AIS patients were recruited and categorized according to their chronological ages (i.e., the 11-year-old group [age from 10.50 to 11.49 years]). The distribution of patients according to their chronological ages is shown in Table 1.

On the standing postero-anterior X-ray film of the spine taken at the first anthropometric measurement visit, curves on coronal plane were identified; the scoliotic curve pattern was then determined based on the apex of the primary curve (i.e., the major thoracic curve, major thoracolumbar curve, major lumbar, double thoracic curve, double major

Table 1 Distribution of the male AIS patients and their controls by chronological age and curve type

Age (years)	Number of subjects		Age (years)		Curve types of AIS				
	Control	AIS	Control	AIS	MT	TL	ML	DT	DM
11	12	10	11.0 ± 0.3	11.1 ± 0.3	5	2	0	0	3
12	13	10	11.9 ± 0.3	11.9 ± 0.2	5	3	1	0	1
13	25	22	13.0 ± 0.3	13.0 ± 0.2	11	5	4	0	2
14	41	40	14.0 ± 0.3	14.0 ± 0.3	18	7	6	3	6
15	91	82	15.0 ± 0.3	15.0 ± 0.3	38	9	13	1	21
16	85	79	15.9 ± 0.3	15.9 ± 0.3	35	8	15	5	16
17	50	47	16.9 ± 0.3	16.9 ± 0.3	18	7	10	5	7
18	25	23	17.7 ± 0.2	18.0 ± 0.3	10	5	4	1	3
19	14	19	18.9 ± 0.3	18.9 ± 0.3	8	2	2	1	6

MT major thoracic curve, *DM* double major curve, *TL* thoracolumbar curve, *ML* major lumbar curve, *DT* double thoracic curve

curve and triple curve) [13]. The Cobb angle of the major curve was selected to determine the curve severity of the AIS patients.

A total of 1,594 anthropometric measurement records of healthy boys from ten local primary and middle schools were reviewed, and comparable numbers of subjects with matched chronological ages were randomly selected as controls. Using a scoliometer, each participant was examined by experienced spine surgeons (X. S., XS. Q. and Z. L.) using Adam's forward bending test to rule out the presence of any spinal deformities [14, 41]. The study was approved by the University and Hospital Research Ethics Committee.

Anthropometric measurements

Standard procedures were followed to measure the body weights, standing heights and arm spans, with the participants wearing only light clothes and no shoes [6, 23]. Body weights were measured to the nearest 0.1 kg using a standardized scale. Body heights were measured with the subjects standing upright against a wall-mounted stadiometer, with their heads positioned in the Frankfort horizontal plane and their heels against the stadiometer. Arm spans were measured using a wall-mounted tape measure with subjects arms fully stretched horizontally and parallel to the tape measure. The readings of both the body heights and arm spans were taken to the nearest 0.1 cm. The body mass index (BMI) of the healthy boys were calculated as the weight (kg) divided by the height (m) squared (kg/m^2). In the AIS patients, corrected height was computed by adjusting the trunk loss using Bjure's equation [3] ($\log y = 0.011x - 0.177$, where y is the reduction in trunk height (cm) caused by the spinal deformity, and x is the Cobb angle of the primary curve). Next, the corrected height was used for calculating the BMIs of the AIS patients. Based on the BMI percentile curves for Chinese children (7–18 years) [19], the BMI percentiles of the patients with AIS and the healthy boys with a chronological age of <18 years were calculated. The subjects were then defined as underweight (a BMI percentile for one's age at or below the fifth percentile), normal weight or overweight (a BMI percentile for one's age above the 85th percentile), according to the guidelines from the Centers for Disease Control and Prevention (http://www.cdc.gov/healthyweight/assessing/bmi/childrens_bmi/about_childrens_bmi.html).

Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (version 12.0; SPSS, Inc., Chicago, IL). All of the parameters are presented as means and standard deviations. A multivariable analysis of variance was performed to determine the effect of disease and chronological age on the anthropometric data; an independent-samples student's t test was then used to test the inter-group differences in the anthropometric parameters for each age group. The incidences of overweight and underweight in the two groups were compared using Chi-square tests. Multivariate regression analysis was conducted to identify the variables that influence the curve magnitude. Furthermore, the anthropometric measurements of the AIS patients with various curve patterns were compared via a multivariable analysis of variance. In this study, the overall statistical significance level was set at $p < 0.05$.

Results

Of the 332 male AIS patients, curve patterns included major thoracic curve in 148 cases, thoracolumbar curve in 48 cases, major lumbar curve in 55 cases, double thoracic curve in 16 cases and double major curve in 65 cases. No triple curves were found in this study. A detailed distribution of the curve types in each age group is shown in Table 1. The Cobb angles of the main curves in the male AIS patients ranged from 10 to 130°, with an average of 30.4° ± 13.1°.

Anthropometric measurements versus chronological age

The body heights, corrected body heights, weights and arm spans of the male AIS patients and their healthy controls are summarized in Table 2. A multivariable analysis of variance revealed significant differences in the body weights, arm spans and BMIs of the AIS subjects and their controls. A comparison of the anthropometric measurements of the AIS subjects and their healthy controls was then performed for each age group. The results show that the arm spans of the male AIS subjects and their controls were comparable in each group. In addition, despite the fact that a significantly lower standing height was found in the AIS patients compared with the normal controls at 18–19 years of age, the standing heights of the controls was not significantly different when compared with the corrected standing heights of the AIS patients.

No significant difference in body weight was found between the AIS boys and their matched controls in the 11–14 age group; however, the body weights of the AIS subjects were significantly lower than those of the healthy boys between the ages of 15 and 19. In addition, the BMIs of the AIS patients between the ages of 15 and 17 were also

Table 2 Comparison of the anthropometric measurements of the male AIS patients and their controls by chronological age

Age (years)	Weight (kg)		Height (cm)			Arm span (cm)		BMI (kg/m^2)	
	Control	AIS	Control	AIS	cAIS	Control	AIS	Control	AIS
11	42.3 ± 8.3	37.4 ± 9.5	147 ± 6.8	145.7 ± 6.7	146.8 ± 6.7	143.1 ± 9.2	144.8 ± 8.3	19.5 ± 3.4	17.1 ± 2.9
12	45.8 ± 10.9	47.1 ± 13.6	153.7 ± 8.6	155.1 ± 12.9	156.2 ± 12.9	149.8 ± 7.2	156.8 ± 16.7	19.1 ± 3	18.8 ± 2.9
13	45.5 ± 10.9	47.0 ± 9.3	156.7 ± 11	159.1 ± 7.1	160.2 ± 7.1	155.2 ± 11.6	159.9 ± 7.6	18.3 ± 2.7	18.2 ± 2.8
14	50.1 ± 9.6	49.8 ± 7.6	163.6 ± 7.1	165.1 ± 7.4	166.3 ± 7.4	164.8 ± 7.1	167.1 ± 7.8	18.6 ± 2.9	17.9 ± 1.9
15	57.8 ± 9.9	53.6 ± 7.4**	170.5 ± 7.6	169.6 ± 6.4	170.8 ± 6.4	171 ± 8.5	171.1 ± 7.4	19.8 ± 2.9	18.3 ± 2.2***
16	60 ± 10.9	55.2 ± 6.9**	171.4 ± 5.6	170.3 ± 6.9	171.5 ± 6.9	172.1 ± 6.6	172.7 ± 8.7	20.4 ± 3.4	18.7 ± 2.2***
17	58.5 ± 7.4	55.5 ± 8.1*	172.6 ± 5.1	170.8 ± 7.7	172 ± 7.7	172.4 ± 7	173.2 ± 8.5	19.7 ± 2.5	18.6 ± 1.9*
18	60.5 ± 7.5	56.4 ± 5.5*	173.2 ± 4.3	169.9 ± 5.7*	171.2 ± 5.6	173.5 ± 8.4	170.8 ± 7.6	20.2 ± 2.3	19.2 ± 1.7
19	64.2 ± 6.8	57.9 ± 9.8*	176 ± 2.9	172.6 ± 6.0*	173.8 ± 6	177.1 ± 5	176.7 ± 6.2	20.7 ± 1.7	19.1 ± 2.3

cAIS corrected height of the AIS

The data from the AIS patients and their controls were compared using student's *t* test, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3 BMI distribution of both the male AIS patients and their control subjects

	Percentile of BMI		
	<5%	5–85%	>85%
Control	12 (3.4%)	293 (84.2%)	43 (12.4%)
AIS	22 (6.8%)	288 (88.6%)	15 (4.6%)

Seven AIS patients and 6 normal patients who were older than 19.0 years with no BMI percentile were not included

The AIS patients and their controls were compared using the chi-square test (chi-square = 15.734, $p < 0.001$)

significantly less than those of the control subjects (Table 2). Based on the BMI percentiles of Chinese adolescents [19], 3.4 and 12.4% of subjects in the control group were defined as underweight and overweight, respectively. However, in the AIS patients, the incidences of underweight and overweight were 6.8 and 4.6%, respectively. Significant differences in these incidences were observed between the AIS patients and their controls (Table 3).

Anthropometric measurements versus curve severity

Multiple regression analysis using a stepwise model was performed on the curve severity with respect to the chronological age and anthropometric data. Body weight and chronological age were found to be significantly and independently associated with the curve severity (Table 4). The Cobb angle was positively correlated with chronological age but negatively correlated with body weight.

Table 4 Multivariate regression analysis of the variables influencing the curve magnitudes of male AIS patients

Variable	Coefficient	Cobb	Adjusted R^2
Body weight (kg)	−0.243	$p < 0.001$	0.056
Age (years)	0.221	$p < 0.001$	

Anthropometric measurements versus curve patterns

To investigate whether the anthropometric data from the AIS patients differed with the patients' various curve patterns, the patients were sub-grouped according to their curve patterns (i.e., thoracic [including main thoracic and double thoracic curves], double major and thoracolumbar/lumbar curves) and their sample size was 164, 65 and 103, respectively. A multivariable analysis of variance revealed no significant difference in the anthropometric data from the AIS patients with various curve patterns. However, there was a significant difference in the Cobb angle in the various curve patterns. The Cobb angles of the patients with thoracic curves and double major curves were significantly greater than those with thoracolumbar and lumbar curves ($p < 0.05$).

Discussion

Sexual dimorphism has been observed in the natural history of AIS during puberty. Compared with female AIS patients, male cases exhibit a lower tendency towards curve progression [4, 38, 39] and a poor response to brace treatment [10, 12, 45]. Because the progression of scoliosis in AIS patients has been shown to be associated with growth during puberty [7, 8, 16, 32, 43, 44], a thorough knowledge of the pubertal growth patterns of male AIS patients is critical for understanding these gender-based discrepancies in the natural history of patients with AIS. However, the literature contains inadequate information concerning the growth of male AIS patients during puberty, which might be due to the rarity of these patients. Hence, the anthropometric measurements of 332 male AIS patients and 356 age-matched control boys were compared in this study.

The results of this study demonstrate that the corrected standing heights and arm spans of male AIS patients are similar to those of their matched controls during puberty. However, compared with the matched controls, the male AIS patients exhibited significantly lower body weights at the age of 15 and thereafter. The male AIS patients also exhibited significantly lower BMIs between the ages of 15 and 17. Additionally, a significantly higher incidence of underweight was observed in the male AIS patients compared with the control group. These findings suggest that the growth of male AIS patients during puberty is different from that of healthy boys and support our hypothesis that male AIS patients have abnormal growth patterns during puberty.

Abnormal pubertal growth has been reported in female AIS patients [30]. Upon comparison with age-matched control girls, Cheung et al. [30] found that female AIS patients exhibit significantly greater corrected standing heights between the ages of 13 and 15 and significantly longer arm spans between the ages of 12 and 15. However, these differences were not significant when the girls reached 16 years of age (i.e., when they were thought to be skeletally mature). This study found that the male AIS patients exhibited similar corrected standing heights and arm spans in most of the age groups when compared with their age- and gender-matched controls. These data imply that there might be no abnormal longitudinal growth patterns in male AIS subjects during puberty. Faster longitudinal growth has been thought to contribute to the significant curve progression of female AIS patients during puberty [7, 8, 18, 43]. However, in male AIS patients, neither standing height nor arm span was identified as independently associated with curve severity. These data may help explain the basis for the lower incidence of curve progression in male AIS patients compared with female patients [11, 18, 34].

A frequent characteristic of girls with AIS is that they have significantly lower body weights compared with their healthy controls during the early and middle pubertal stages [1, 21, 30]. Cheung et al. [30] reported significantly lower body weights and BMIs in AIS girls compared with their healthy controls between the ages of 12 and 15. Recently, Barrios et al. [1] reported that scoliotic girls have significantly lower mean weights and BMIs compared with those in a control population. The AIS girls also exhibited progressive decreases in their BMIs as their ages increased during puberty. A total of 21.2% of the AIS girls could be considered anorexic (BMI < 17.5), while the incidence in control group was only 3.3% [1]. However, these differences may no longer be significant when the patients reach skeletal maturity [30]. In this study, significantly lower body weights and BMIs were found in the male AIS patients compared with the controls after the onset of pubertal growth. These findings strongly support our hypothesis that, although both the male and female AIS patients exhibited abnormal pubertal growth, the male AIS patients exhibited a different pattern of abnormalities compared with the female AIS patients. The increased incidence of lower body weight in girls with AIS has been ascribed to disordered eating behavior [15, 31], which might be due to a disturbed body image caused by the spinal deformity and other factors [31]. Because our study was retrospective in nature, the nutritional statuses of the recruited patients were unavailable. Whether these factors also play a role in the lower body weights of male AIS patients should be investigated further.

In girls with AIS, stepwise multiple regression analysis revealed several significant independent anthropometric variables that predict curve severity, including arm span, sitting height, log-transformed BMI and age (but not body weight) [5]. In contrast, in this study, a multivariate regression analysis showed that body weight and chronological age serve as independent predictors of curve magnitude in male AIS patients. These results indicate that the more severe the abnormality in body weight (thinner) and the younger the male AIS patient, the greater is the risk for curve progression. These findings suggest that, in addition to chronological age, body weight might serve as a prognostic factor for curve severity in male AIS patients. In the future, longitudinal studies should be conducted to further validate this finding.

The incidence of curve progression was found to vary according to the curve pattern [18, 33]. In male idiopathic scoliosis patients, Soucacos et al. [33] found that the right lumbar curve had the highest incidence of curve progression, followed by the single right thoracic, left lumbar, thoracolumbar curves and double curves. By sub-grouping the male AIS patients in our study according to their curve patterns, the multivariable analysis revealed no inter-group differences in their anthropometric measurements. These findings imply that factors other than longitudinal growth might play roles in determining the characteristics of curve progression in male AIS patients with various curve patterns.

In this study, chronological age (but no other parameter) was selected to represent the pubertal growth status. Some previous studies have reported that chronological age might be an inaccurate indicator of skeletal maturity in patients with AIS [9, 30, 40]. However, the results of several other studies have identified chronological age as a variable that predicts skeletal maturity and curve progression in AIS [16, 18, 22]. During the subsequent study of the growth patterns of male AIS subjects, several other parameters could be used to reflect maturity, including the Risser sign [2, 20, 29, 36], the digital skeletal age (DSA) [27, 28] and Tanner's pubertal stages [30]. Second, as in any other cross-sectional study, no definitive conclusion concerning the evolution of the anthropometric parameters over time can be drawn. A longitudinal study would enable the accurate assessment of the growth patterns of AIS boys and their healthy controls, the association between curve progression and anthropometric parameters and the prognostic value of body weight with respect to curve progression in male AIS patients.

In summary, the anthropometric measurements of 332 male AIS patients and 356 matched controls were compared. For the first time, this study reported abnormal pubertal growth patterns in male AIS patients. In addition, we also found that the abnormality patterns of male AIS patients were different from those reported previously for female AIS patients. The male AIS patients exhibited comparable arm spans, standing heights and corrected standing heights compared with the healthy boys. The lack of abnormal longitudinal growth may explain, in part, the mechanism of the lower incidence of curve progression in male AIS patients. However, persistently lower body weights and BMIs were observed in the male AIS boys older than 14 years of age until they reached skeletal maturity. Body weight and chronological age served as the most important variables that influence curve magnitude in male AIS subjects. These findings indicate that body weight might be a prognostic factor for spinal deformity in male AIS patients. Based on this cross-sectional study, a longitudinal study to confirm these findings and presumptions is warranted. In addition, this study should be replicated in an independent cohort and, preferably, involve several other growth parameters (e.g., Tanner pubertal stages).

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Conflict of interest None of the authors has any potential conflict of interest

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