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ORIGINAL ARTICLE

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Assessment of curve progression in idiopathic scoliosis

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Abstract In a 5-year prospective study on idiopathic scoliosis, an attempt was made to elucidate the natural history of the disease and to determine which factors contribute to curve progression. A total of 85,622 children were examined for scoliosis in a prospective school screening study carried out in northwestern and central Greece. Curve progression was studied in 839 of the 1,436 children with idiopathic scoliosis of at least 10° detected from the school screening program. Each child was followed clinically and roentgenographically for one to four follow-up visits for a mean of 3.2 years. Progression of the scoliotic curve was recorded in 14.7% of the children. Spontaneous improvement of at least 5° was observed in 27.4% of them, with 80 children (9.5%) demonstrating complete spontaneous resolution. Eighteen percent of the patients remained stable, while the remaining patients demonstrated nonsignificant changes of less than 5° in curve magnitude. A strong association was observed between the incidence of progression and the sex of the child, curve pattern, maturity, and to a lesser extent age and curve magnitude. More specifically, the following were associated with a high risk of curve progression: sex (girls); curve pattern (right thoracic and double curves in girls, and right lumbar curves in boys); maturity (girls before the onset of menses); age (time of pubertal growth spurt); and curve magnitude (≥ 30°). On the other hand, left thoracic curves showed a weak tendency for progression. In conclusion, the findings of the present study strongly suggest that only a small percentage of scoliotic curves will undergo progression. The pattern of the curve according to curve direction and sex of the child was found to be a key indicator of which curves will progress.

Key words Idiopathic scoliosis · Curve progression · School screening

Introduction

A major concern of orthopedic surgeons in managing children with idiopathic scoliosis with a minor curvature is identifying how many and which curves will progress to severe deformities requiring treatment [1, 3–12, 14, 15]. Accurate identification of curves destined to progress requires a clear understanding of the natural history of idiopathic scoliosis. In this regard, school screening has been a powerful tool for the identification of children who may have scoliosis, as well as for providing information on the course of the disease over time [10, 11, 15, 17–19, 21, 22]. The vast majority of the children, however, show no spinal deformity, and of the scoliotic curves detected through school screening, only a percentage are destined to progress to clinical significance. Various factors have been associated with curve progression, although it is not clear to what extent they can be used in predicting the course of the natural history of the scoliotic curve. As a result, definitive guidelines have yet to be established that can assist the surgeon in assessing the risk of progression for each child.

The present report represents the last phase of the 5-year prospective study done to assess the prevalence and distribution of various parameters associated with scoliosis in 82,901 school children in northwestern and central Greece. The purpose of the current study was to assess curve progression in untreated idiopathic scoliosis, with the aim of elucidating the natural history and behavior of the scoliotic curve and assessing which factors can be taken into account for predicting curve behavior. Curve progression was studied from multiple, consecutive follow-up examinations of 839 untreated scoliotic children diagnosed with idiopathic scoliosis of at least 10° from the population of school children screened in the prefecture of the Ioannina University Hospital, with a mean follow-up period of 3.2 years.

Patients and methods

The present report is the last segment of a five-phase prospective study on idiopathic scoliosis, which has extended over the last 5 years, performed by the Scoliosis Unit of the Department of Orthopedic Surgery of the Univeristy of Ioannina, School of Medicine. The first phase entailed a 2-year school screening study, which was done to assess the prevalence rate and distribution of various parameters associated with scoliosis in school children aged 9–15 years in northwestern and central Greece. Scoliosis screening was done in a total of 85,622 school children from five major geographical areas, including Northern Epirus (2,721), Ioanian Islands (6,699), Etolo-Akarnania (16,743), Epirus (21,415) and Thessalia (38,044). Children with signs of scoliosis (n = 5,867) underwent clinical re-evaluation in a second phase. The third phase of the study involved roentgenographic evaluation of children (n = 4,185) who, in the second phase, were identified as having a difference between the two sides of the torso at the thoracic or lumbar level greater than 5 mm in the Adam's forward-bending test. A total of 1,682 children (including those from Northern Epirus, those in whom scoliosis was not clinically confirmed, and those who dropped out from the study) were excluded from the third and subsequent phases. In the third phase, 1,436 children were identified with a scoliosis measuring 10° or more, and in the fourth phase, a number of parameters associated with scoliosis were assessed.

School screening

Scoliosis screening teams, each consisting of a senior orthopedic surgeon and staff member, an orthopedic resident, a nurse, and a medical student, were organized and trained both in screening methods and child behavior. Screening took place in the physical education class and usually with the assistance of the physical education instructor. Boys and girls were examined separately in their familiar class groups. Boys were asked to wear shorts, while the girls wore shorts, bra or a loose T-shirt, which could be lifted during examination.

Parameters recorded included:

1. Biographical information: name, date of birth/age, address, parents' age and occupation, number and gender of siblings
2. Physical characteristics: hair and eye color, body frame (large, medium or small), age at menarche in girls and rough indication of pubertal stage in boys (as indicated by the degree of pubic/body hair), weight, standing and sitting height, and arm span length
3. Spinal screening: rib or lumbar humps, shoulder or hip discrepancies, and torso or spinal imbalance

Rescreening, radiographic evaluation, and management

Positive signs for scoliosis included asymmetrical shoulder levels, scapular prominence, unequal distance from arms to flanks or lower limb inequality in the standing position, and lateral deviation of the spine in the Adams forward-bending test. Children with a positive screening were re-evaluated by a senior orthopedic surgeon in order to confirm criteria for referral. Children suspected of scoliosis were requested to present themselves to the team for re-evaluation that same afternoon. Upon re-evaluation, the child was submitted to a second forward-bending test. The examiner compared the two sides of the child's torso at both the thoracic and thoracolumbar levels. If any difference in height between the two sides (right vs left) was noted, it was measured using a level plane and ruler. A difference in the heights of the sides exceeding 5 mm was considered a positive bending test. It should be noted that although most surgeons agree that no differences exist between screening in the sitting and standing position in terms of lower limb equalities resulting from hamstring shortening, the bending test in a sitting position with the knees bent has been reported to avoid false suspicion of rotation of the spine [16].

Thus, the child was referred for radiographic evaluation if the examiner confirmed a positive Adam's test with a difference between the two sides at the thoracic or lumbosacral level greater than 5 mm or the presence of any of the physical signs noted above. Thus, the criterion for radiographic evaluation was a positive finding by the examiner in a second re-check screen. Only after a re-check, were positive cases referred for standing posteroanterior radiographs, which were taken and assessed immediately. A curve measuring greater than 10°, using the Cobb method, was defined as a structural scoliosis according to the Scoliosis Research Society criteria [21]. Only children with structural curves greater than 10° were included in the study. The course of treatment for each child was based on the magnitude of the scoliotic curve.

We found that:

1. Of 82,901 children analyzed (the 2,721 children from Northern Epirus were excluded), the prevalence rate of children with scoliosis was 1.7%, with the majority of cases being accounted for by small curves.
2. The male to female ratio was 1:2 overall, but varied according to the magnitude of the curve.
3. Thoracolumbar and lumbar curves were more common than thoracic curves.
4. The ratio of left to right curves varied according to location, with the majority of thoracic curves being right and the thoracolumbar and lumbar being left [19].

Follow-up study of the natural history of progression

The natural history of scoliosis was studied in 839 children from the prefecture of the University Hospital, out of the 1,436 children diagnosed with idiopathic scoliosis by the school screening program in northwestern and central Greece during 1993 and 1994. Of the 1,436 children identified with scoliosis, 69 (9 boys, 60 girls) were treated conservatively, while 8 (2 boys, 6 girls) underwent surgical management. Children who underwent conservative or surgical management were excluded from the analysis on curve progression.

Of the 839 children followed for curve progression, there were 231 boys (27.5%) and 608 girls (72.5%). The age of the patients is shown in Fig. 1. The magnitude of the scoliotic curve at the initial evaluation was 10°–14° in 541 patients, 15°–19° in 169, 20°–24°

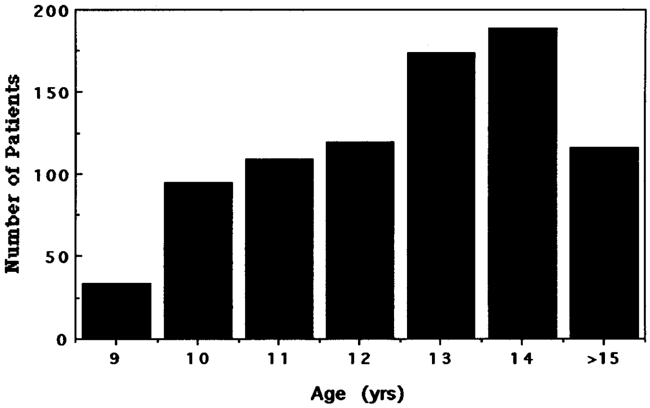

Fig. 1 Age distribution of the 839 patients studied

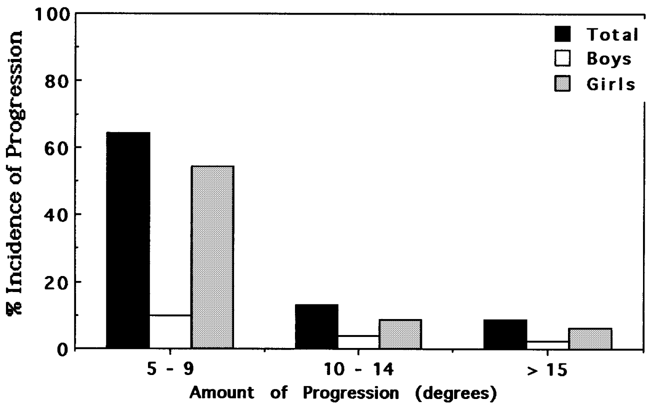

Fig. 2 Percentage incidence of progression in children (total, boys and girls) according to the amount the curve had progressed (5°–9°, 10°–14°, and ≥ 15°). The majority of the curves showed a progression between 5° and 9°. Note the difference between girls and boys according to the amount that the curve had progressed; the vast majority of curves that progressed less than 10° were in girls

in 87, 25°–29° in 15, and ≥ 30° in 27 patients. The curve pattern was a double curve in 134 of the children, while 148 had single thoracic, 259 had lumbar, and 298 had thoracolumbar curves. Each student with scoliosis was followed clinically and roentgenographically for one to four follow-up visits for a mean of 3.2 years. Children with curves greater than 30° were followed for at least two visits, up until the initiation of treatment, after which they were excluded from the study.

Progression of the curve was defined as an increase of 5° or more as measured by the Cobb method over two or more visits. Factors that were assessed for association to progression of the curve included sex, age, maturity (menarche for girls), curve pattern, and curve magnitude.

Data analysis

All parameters were recorded on a Macintosh computer using a spreadsheet designed for this purpose (Claris Filemaker Professional, Microsoft, Calif.). Statistics were done using the Statview II (Microsoft) statistical package. The risk of progression was correlated with the magnitude and the pattern of the curve at the time of presentation with the use of the Kolmogorov-Smirnov test for ordinal data. The magnitude of the curve was categorized as 10°–19°, 20°–29°, or greater than 30°, while the curve pattern was coded and categorized as 1 (double curve), 2 (R thoracic), 3 (L thoracic), 4 (R thoracolumbar), 5 (L thoracolumbar), 6 (R lumbar), or 7 (L lumbar). Chi-square (χ^2) tests were performed on categorical data.

Results

Curve progression

The natural history of scoliosis was assessed from follow-up examinations of 839 children diagnosed with scoliosis of 10° or greater from 85,622 children screened. Of the 839 patients, 123 (14.7%) demonstrated progression of the curve of at least 5°. The percentage incidence of progression was significantly greater in girls (16.6%, n = 101) than in boys (9.5%, n = 22) (χ^2, $P \leq 0.05$).

In contrast, 230 children (27.4%; 99 boys and 131 girls) showed an improvement in the curve of 5° or more between the initial visit and the final follow-up, while 151 (18%; 33 boys and 118 girls) remained stable. The remaining patients showed insignificant changes in curve magnitude.

Of the 123 children who demonstrated progression of the curve, the majority showed an amount of progression that was between 5° and 9° (Fig. 2). The amount of curve progression varied greatly between boys and girls.

Eighty patients (9.5%; 33 boys and 47 girls) showed complete spontaneous resolution of the scoliotic deformity. The patients who demonstrated a decrease in curve magnitude were similar in age to those who had curve progression (mean age 11.9 and 12.5 years vs 12 and 12.5 years for boys and girls, respectively). However, the size of the scoliotic curve at the first visit was smaller in those children who demonstrated improvement (11.7° and 13.6° for boys and girls, respectively) than in those who showed progression of the curve (16.7° and 16.4° for boys and girls, respectively).

Factors related to curve progression

Sex

Of the 839 children with scoliosis, the incidence of progression in boys was 2.6% (n = 22) compared to 12% in girls (n = 101). The sex difference in progression was most notable in children who showed curve progression of between 5° and 9°. On the other hand, no significant difference between boys and girls was observed when progression greater than 10° had occurred (Fig. 2).

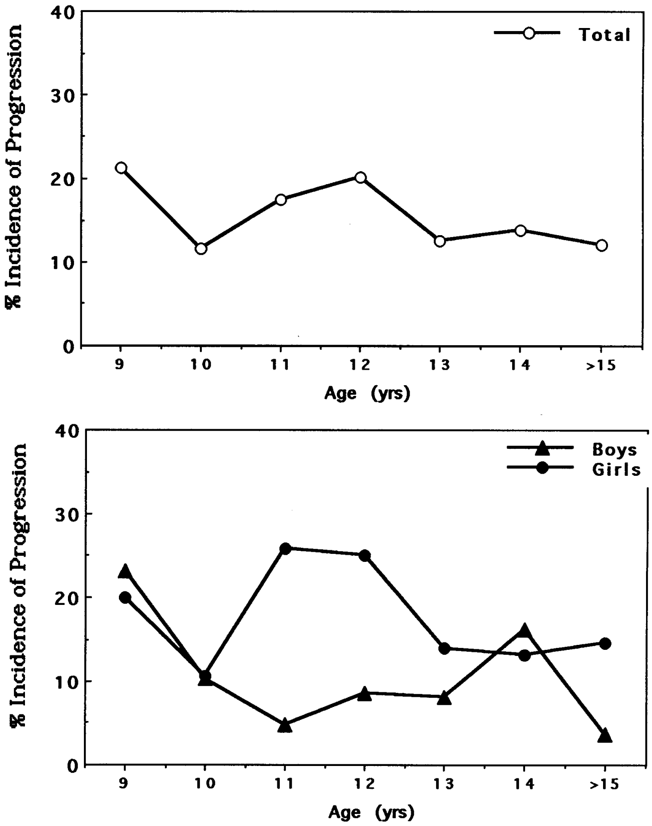

Fig. 3 Incidence of curve progression according to the age of the patient when first examined for all children (*top panel*) and boys and girls separately (*bottom panel*). Note that both boys and girls demonstrate a small peak in the incidence of progression at the time of the pubertal growth spurt

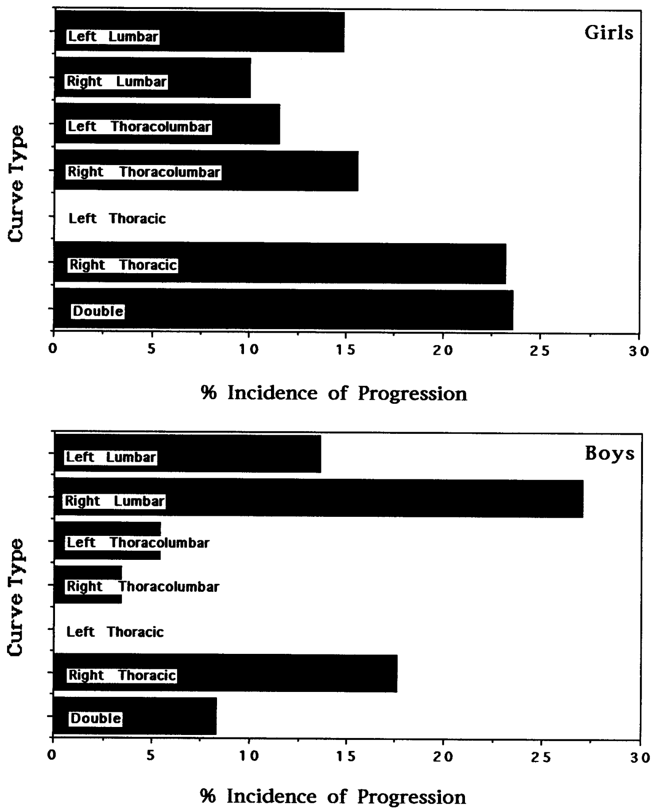

Fig. 4 Incidence of curve progression according to the curve pattern and direction (left vs right) for girls (*top panel*) and boys (*bottom panel*). Note that none of the left thoracic curves showed progression. The incidence of progression of right thoracic curves in girls was as high as that observed for double curves; boys with right lumbar curves had a higher incidence of progression than girls

Age

The incidence of progression was found to vary with age (Fig. 3). Both boys and girls demonstrated a small, but notable peak in the incidence of progression at the time of the pubertal growth spurt (11–12 years old for girls; 14 years old for boys).

Menses

Menarche had occurred in only 35.6% of the girls with progressive curves (n = 101), while of the girls who had improvement or remained stable (n = 507) menarche had occurred in 52.3% (χ^2; $P \leq 0.05$).

Curve pattern

The incidence of progression was found to vary significantly according to the pattern of the curve, with double curves showing a higher incidence of progression (21%), followed by thoracic (16.9%), lumbar (14.3%), and then thoracolumbar curves (10.1%). There was a notable difference in the incidence of progression between boys and girls for double and thoracolumbar curves (double curves: 8.3% vs 23.6% and thoracolumbar curves: 4.9% vs 12.9% for boys and girls, respectively).

The direction of the curve (left vs right) for each type was found to play an important role in curve progression, particularly when considered in association with the sex of the child (Fig. 4). None of the left thoracic curves showed progression over the 3.2-year follow-up period, while the incidence of progression of right thoracic curves (22%) was as high as that observed for double curves. Both boys and girls with right thoracic curves demonstrated a high incidence of progression (17.6% and 23.2%, for boys and girls, respectively). On the other hand, while girls with right and to a lesser extent those with left thoracolumbar curves showed a higher incidence of progression than boys, boys with right lumbar curves (n = 15) demonstrated a higher incidence of progression (27%) than girls (10%, n = 50). The relationship between curve

Table 1 Natural history of the scoliotic curve according to curve type and direction

Curve Type	Progressed (%)	Stable (%)	Improved (%)
Thoracic			
Right (n = 116)	21.6	58.6	19.8
Left (n = 32)	0	62.5	37.5
Thoracolumbar			
Right (n = 93)	11.8	47.3	40.9
Left (n = 205)	9.3	43.9	46.8
Lumbar			
Right (n = 65)	13.8	75.4	10.8
Left (n = 193)	14.5	67.4	18.1
Double (n = 134)	20.9	64.9	14.2

Table 2 Features associated with complete, spontaneous resolution of the scoliotic curve in 80 patients

Curve type	n	Curve magnitude	n
Right thoracic	1	10°	38
Left thoracic	15	11°	20
Right thoracolumbar	10	12°	5
Left thoracolumbar	33	13°	7
Right lumbar	4	14°	2
Left lumbar	13	15°	5
Double	4	17°	2
		18°	1
Total	80		80

pattern and progression was significant (Kolmogorov-Smirnov test, $P \leq 0.05$).

On the other hand, it is noteworthy that left thoracic, as well as left and right thoracolumbar, curves were associated with a high percentage of curve improvement (38%, 47%, and 41%, respectively) (Table 1). Moreover, a large percentage of these patients (34%, 38%, and 39%, respectively) showed a decrease in the magnitude of the curve of 10° or greater. Of the 80 children who demonstrated complete spontaneous resolution of the scoliotic deformity, 41% (n = 33) had left thoracolumbar curves and 78.8% (n = 63) had an initial curve magnitude of between 10° and 12° (Table 2).

Magnitude of the curve

Overall, the greater the magnitude of the initial curve, the greater the incidence of progression (Fig. 5). The increase in the percentage of patients showing progression was moderate for curves in the range 10°–20° (11.9%–20%). However, for curves greater than 30°, the incidence of progression increased significantly (48%). No difference between boys and girls was observed. The relationship between the magnitude of the curve and progression was significant (Kolmogorov-Smirnov test, $P \leq 0.05$).

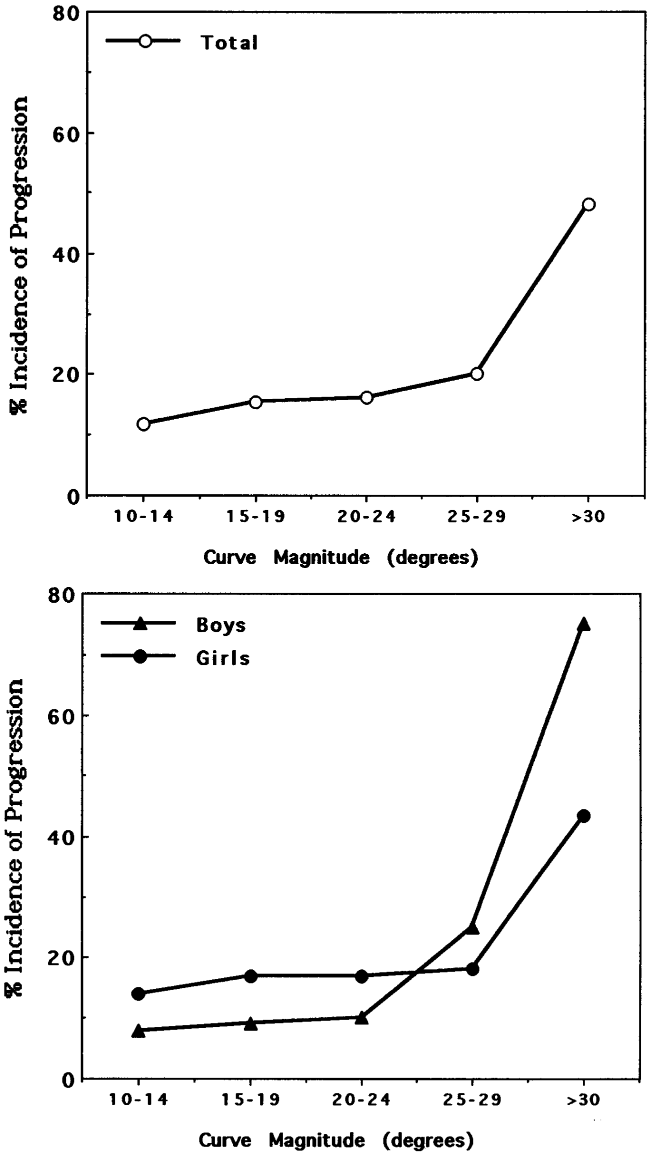

Fig. 5 Incidence of progression according to the magnitude of the initial curve for all children (*top panel*) and boys and girls separately (*bottom panel*). The incidence of progression increases only moderately for curves between 10° and 20°, and more so for curves ≥ 30°. Note that there is no difference between boys and girls

Age and magnitude of the curve

The incidence of progression did not appear to be significantly related to the magnitude of the curve and the child's age (Table 3).

Table 3 Progression of the curve according to initial curve magnitude and patient's age

Age (years)	Progression					
	10°–19°		20°–29°		≥ 30°	
	%	(*n*)	%	(*n*)	%	(*n*)
≤ 10	11.7	(120)	12.5	(8)	75.0	(4)
11–12	15.2	(198)	33.3	(21)	44.0	(9)
13–14	11.7	(307)	13.3	(45)	50.0	(10)
≥ 15	11.9	(84)	10.7	(28)	25.0	(4)

Table 4 Progression of the curve according to curve type and magnitude

Curve type	Curve magnitude	Percentage progression (*n*)	
		Boys	Girls
Thoracic			
Right	10–19°	11 (28)	22 (65)
	20–29°	25 (4)	18 (11)
	≥ 30°	50 (2)	50 (6)
Left	10–19°	0 (11)	0 (18)
	20–29°	0 (0)	0 (3)
	≥ 30°	0 (0)	0 (0)
Thoracolumbar			
Right	10–19°	4 (28)	14 (59)
	20–29°	0 (1)	33 (3)
	≥ 30°	0 (0)	0 (2)
Left	10–19°	5 (74)	11 (118)
	20–29°	0 (0)	17 (12)
	≥ 30°	0 (0)	0 (1)
Lumbar			
Right	10–19°	27 (13)	12 (43)
	20–29°	0 (2)	0 (7)
	≥ 30°	0 (0)	0 (0)
Left	10–19°	13 (40)	14 (123)
	20–29°	25 (3)	24 (25)
	≥ 30°	100 (1)	0 (2)
Double	10–19°	5 (19)	24 (72)
	20–29°	0 (4)	15 (27)
	≥ 30°	0 (0)	50 (12)

Type and magnitude of the curve

The incidence of progression varied according to the type and magnitude of the curve (Table 4).

Miscellaneous

The school screening program covered a large geographical region in northwestern and central Greece, including isolated rural and dense urban areas. Of the 85,627 children screened, 69.2% were from urban areas, while 30.8% were from rural areas. Although, of the children identified with scoliosis, 35% were from rural areas and 65% were from urban areas, the incidence of progression was slightly higher in patients from rural areas (15.6%) than in those from urban areas (13.6%). No association between progression and parental age, number of siblings, hair and eye color, or height were observed.

Discussion

Despite a number of studies, the natural history of idiopathic scoliosis and the risk of curve progression remains obscure. The incidence of progression in different reports varies according to the criteria of progression, inclusion of patients undergoing treatment, and length of follow-up [5, 7, 9, 11, 14, 20]. In a prospective screening study, Brooks et al. [1] reported a 5% incidence of progression in 134 children with a scoliosis of 5° or more, and a spontaneous improvement in 22%. In cases detected through screening, Rogala et al. prospectively followed 603 children for at least 2 years and found that 6.8% of the curves progressed 5° or more [17]. Of 81 children who had suffered untreated idiopathic scoliosis for at least 3 years, Fustier observed a progression of 5° or more in 56% of the patients with an initial curve of 10°–29° and in 75% of those who had an initial curve of 20°–29° [6]. In an extensive study, Nachemson et al. reported that girls with untreated scoliosis of 20°–29° who were 10–12 years old had a 60% risk of progressing at least 5° [13]. The incidence increased to 90% for girls who had curves of 30°–59°, and the incidence of progression was lower for girls aged 13–15 years (40% and 70%, respectively). Nachemson et al. indicated that the remaining growth potential, curve pattern, sex, and curve magnitude were all related to curve progression. Lonstein and Carlson, in a retrospective review of cases mainly detected through screening at a scoliosis center, found progression in 23.2% of 727 children with untreated scoliosis [10]. They reported that curve magnitude, skeletal immaturity, and curve pattern were associated with progression. In a retrospective chart review of cases not detected through screening, but meeting specific criteria, Bunnell found that 68% of 123 children suffered curve progression [2].

The present report presents an assessment of untreated scoliotic curve progression based on an extended prospective school screening study. The 14.7% incidence of curve progression found is within the lower range of previous reports. This may be explained, in part, by the fact that many of the previous studies showing a high incidence of progression were retrospective reviews of patients referred for treatment. These studies tend to select larger and more progressive curves, while scoliosis in its earlier stages is usually not represented.

The incidence of spontaneous improvement (27.4%) observed in the present study is similar to that reported by Brooks et al. (22%) [1]. Although the patients who demonstrated spontaneous improvement were similar in age to those who showed progression, they tended to have smaller curves when first screened. Unexpectedly, some children (9.5%) showed complete spontaneous resolution of the scoliotic curve, while over 35% of the patients with left thoracic or left and right thoracolumbar curves showed a spontaneous decrease in the magnitude of their curve of at least 10°.

Significant individual variation was observed in the natural history of the scoliotic curves. Nonetheless, it was possible to isolate several factors that showed a significant influence on the course of curve development.

Sex differences in the risk of progression related to the amount the curve had progressed. Although girls showed a higher incidence of progression overall, the difference between boys and girls was more pronounced with curves that progressed between 5° and 10°.

Previous reports have demonstrated a correlation between age and progression, where the incidence of progression decreases as the child gets older [2, 3, 10, 11, 14]. Others have found that the onset of curve progression coincides with the onset of puberty and the appearance of secondary sex characteristics [12]. Duval-Beaupere points out that the progression of idiopathic scoliosis occurs at the time of most rapid adolescent skeletal growth [4]. The small peak in progression observed in girls around the age of 12 years and in boys around the age of 14 years may be associated with the pubertal growth spurt. The difference in the curves and peaks between boys and girls is underscored by the fact that boys and girls at these ages differ greatly in their growth and development [8].

Although age did not show a direct linear relationship with the incidence of progression, maturity as reflected by menses in girls was clearly associated with progression of the curve. Specifically, curves that developed before menarche in girls had almost twice as great a risk for progression. Previous studies have shown a relationship between the incidence of progression and the Risser sign [2, 3, 10, 11]. The Risser sign, as a scale of ossification of the iliac apophysis, is considered an indirect measure of maturity.

The association of progression and curve pattern observed in the current study was compatible with previous findings [2, 3, 6, 10, 11]. However, the curve pattern according to the direction of the curve as well as the sex of the child was found to play a more important role in assessing the risk for curve progression. In this regard, left thoracic curves were never observed to progress in either sex, but rather showed spontaneous improvement. On the other hand, the incidence of progression for right thoracic curves was as high as that observed for double curves, while both right and left thoracolumbar curves progressed more frequently in girls. Right lumbar curves showed a much greater percentage of progression in boys. The latter is noteworthy, as it is the only situation where boys were found to have a high incidence of curve progression.

The incidence of progression was also found to increase somewhat with the size of the initial scoliotic curve. Previous studies have shown a direct relationship between progression and magnitude of the initial scoliotic curve, where the incidence of progression increased with an increase in curve magnitude [2, 3, 6, 10, 11]. In the present study, only a moderate association was observed for curves up to 29° in magnitude. Since age and curve magnitude independently did not demonstrate strong correlations with progression in this study, it is not surprising that the incidence of progression according to both age and magnitude also did not show a striking association, as has been suggested in previous reports [10, 11, 13].

As children with severe deformities are treated, it is not clear at what point curves stop progressing and stabilize. Nonetheless, several attempts have been made to identify features that may assist the orthopedic surgeon in predicting which scoliotic curves are at risk of progressing to the point of clinical significance, requiring active management. Several studies have suggested that the magnitude of the curve and the child's age and maturity are related to curve progression in idiopathic scoliosis [2, 3, 6, 10, 11, 13]. On the other hand, only a few have suggested a relationship between progression and sex, family history, or pattern of the curve [10, 11, 17].

In the present study, the factors found most important in their association with the natural history of the scoliotic curve were sex of the child, curve pattern, and maturity. More specifically, the pattern of the curve was strongly indicative of the risk of progression when considered according to curve direction and sex of the child. The results of this study indicate that girls with a right thoracic or double curve greater than 10° and who have not reached menarche are at a high risk for progression, while boys with right lumbar curves are also prone to show curve progression. On the other hand, because of their weak tendency to progress, left thoracic curves can usually be considered benign.

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