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THE LENGTH AND PROPORTIONS OF THE THORACOLUMBAR SPINE IN CHILDREN WITH IDIOPATHIC SCOLIOSIS

LARS B. SKOGLAND & JAMES A. A. MILLER

Sophies Minde Orthopaedic Hospital, University of Oslo, Norway.

The length of the thoracolumbar spine was measured on standardized X-ray films from 274 children ($6^1/_2$–$18^1/_2$ years) with idiopathic scoliosis and 212 controls. Where possible, the height and width (transverse diameter) of two vertebral bodies (T-6 and L-4) were also measured.

Although a tendency towards longer spines in the scoliotics could be found, there was no significant difference between children with idiopathic scoliosis and controls in this respect. In girls the pubertal growth-spurt of the spine was found to start about 1 year earlier than in the controls and the growth of the spine seemed to cease later in the scoliotics.

The height and width of T-6 was significantly greater in the scoliotics than in the controls for girls under 13 years of age. In the older girls and in the boys no significant difference could be demonstrated. The height of L-4 tended to be greater in the scoliotic boys and younger girls, though the differences were not statistically significant. The index height/width was calculated for T-6 and L-4 in all groups of patients and higher values could be demonstrated in the scoliotics for all test groups.

The greater height of T-6 in scoliotics might indicate a longer thoracic spine in these children. The higher values of the height/width indices suggest that the thoracolumbar spine in children with idiopathic scoliosis has an increased slenderness compared with the spine in non-scoliotic children.

Key words: adolescence; growth; idiopathic scoliosis; radiography; spinal length; vertebral dimensions

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The association between physical growth and progression of a structural scoliosis is well established (Duthie 1959, Duval-Beaupère et al. 1970) but the mechanism by which growth may influence spinal deformities is still not well understood. Idiopathic scoliosis (IS) seems to develop during periods of rapid longitudinal growth (Willner 1972) and mild to moderate curves (<60 degrees Cobb) usually progress very little after the completion of growth in the spine (Collis & Ponseti 1969).

The aetiology of IS is probably multifactorial and one of the possible factors could be mechanical instability of the spine. If so, spinal length and dimensions of the vertebral bodies and discs may be pertinent geometric factors. Willner (1972) and Nordwall & Willner (1975) have demonstrated that girls with IS are significantly taller than healthy controls, but there is no documentation that the spine as such is longer in these children. Sitting height has been reported to be greater in scoliotic children (Willner 1972) but

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this is not a reliable indicator of spinal length. In addition, the sitting height gives no information regarding the detailed vertebral dimensions.

Brandner (1970) demonstrated in healthy children that vertebral body height/sagittal diameter ratios are larger in girls than in boys and Schultz (1976) has suggested that this could be relevant to the sex-related deterioration of scoliosis.

The objectives of this investigation were to ascertain whether the thoracolumbar spine is longer in IS children than in a control group and to investigate whether there are differences in other dimensions of the vertebral column. At the present time such measurements can only be made on X-ray films.

MATERIAL AND METHODS

At Sophies Minde Orthopaedic Hospital the same standard radiographic examination technique has been used for patients with scoliosis since 1968. An antero-posterior (a–p) exposure of the complete thoracolumbar spine and the upper part of the pelvis is made with the patient in the standing position. The focus-to-film distance is 150 cm with film size being 30 × 60 cm. In addition to the X-ray examination of the spine, a hand X-ray is usually made on the first visit to the clinic in order to determine the skeletal age.

The present material (Table 1) includes patients with IS examined at the hospital from 1969 to 1975. All case histories from this period were examined and the relevant cases were selected according to the following criteria: a chronological age between 6.5 and 18.5 years, X-ray films of the spine and hand from the same visit available, a scoliosis curve not exceeding 40 degrees (Cobb 1948), and progressive scoliosis documented through a series of X-ray films. In the majority of cases treatment had been started after the first examination, but a few patients were under observation due to a relatively late onset. The X-ray films used for measurements had been made before the start of treatment or in some cases (< 10 per cent) after a few months of bracing. All patients with disorders or malformations indicating a diagnosis other than IS were excluded. In all cases the deformity had been diagnosed after the age of 5 years and in the majority of cases after 10 years of age. No distinction was made between juvenile and adolescent types of IS.

The control group (C) included children in the same age groups as the scoliotics who had been examined at the hospital during the period from 1970 to 1978. Radiographic examination of the spine as described above had been carried out because of back problems other than structural scoliosis. Most of the control cases represented children and adolescents with leg length discrepancy and a static scoliosis of the lumbar spine (Table 2). In a great number of the control cases the skeletal age could be determined as well.

All spinal curvatures were measured in degrees according to Cobb (1948). The skeletal age was determined using the Greulich & Pyle (1970) standards. The accuracy of this method was calculated and has been reported separately (Skogland & Eek 1980). The length of the thoracolumbar spine was measured uncorrected (L_{uc}) and corrected (L_c) for the loss of length due to the deformity. L_{uc} was the distance between the centre of the upper endplate of T-1 and the midpoint of a line drawn tangentially to the ala on either side of the sacrum. L_c was determined by measuring the distance between the same points, but along the curvatures as shown in Figure 1. For the measurements of spinal length a machinist's scale was used. In addition the height (H) and width (W) of one representative (see

Table 1. Survey of complete series

				Apex location		Single thoracic curves		Thoraco-lumbar curves		Single lumbar curves			No. of vertebrae		
	Total number of radiograms	Mean age (years chr.)	Mean Cobb angle (°)	mean	mode	left convex	right convex	left convex	right convex	left convex	right convex	double curves	16	17	18
IS ♀	235	13.6	31	T-9	T-8	1	142	19	12	8	4	49	3	229	3
C ♀	172	12.3											5	163	4
IS ♂	39	13.6	29	T-9	T-9	0	34	1	0	1	2	1	0	38	1
C ♂	40	12.1											1	39	0

Table 2. Control group. List of diagnoses

	girls	boys
Leg length discrepancy	66	29
Functional back problems*	56	4
Congenital dislocation of the hip	16	
Anteversion of the femoral neck	10	
Congenital clubfoot	7	1
Others	17	6
	172	40

*Patients referred because of back complaints or "poor posture" and in whom no organic disorders could be found at the first and subsequent examinations.

below) thoracic and lumbar vertebral body were measured. The width of the vertebra was determined by measuring the narrowest part of the "waist" of the vertebral body. The height was defined as the distance between the upper and lower endplates along the perpendicular bisector of the "waist-line". The vertebral body dimensions were measured to the nearest 0.1 mm with a pair of dial calipers. If the outlines of the vertebra were poorly defined the radiogram was excluded from the study.

The data analysis was run on a Digital Equipment Corporation "DEC-10" computer, using a statistical programme ("Stat-Pack", Western Michigan University). Significance testing was carried out using the Mann-Whitney U-test or the Student's t-test where applicable for larger sample sizes (> 30). The two-tailed test was used in all cases. Since the statistical treatment of ratios may produce misleading results (Anderson & Lydic 1977) it was decided against performing any such procedures in the present study.

Reliability of methods. One of the most obvious errors inherent in measurements of this kind is associated with the rotation of the vertebral bodies in a scoliotic spine. However, in the majority of scoliotic spines it is possible to find one or more unrotated vertebral bodies and therefore it was decided to select unrotated vertebrae for these measurements.

In a pilot study on X-ray films from 33 girls and 7 boys with IS, it was found that T-6 and L-4 were the vertebrae most often unrotated in the thoracic and lumbar spine, respectively. All vertebral bodies were classified as unrotated when no asymmetry of the pedicle-shadow offset could be seen. In order to find out how axial rotation, lateral and sagittal tilt might affect the radiographic image, an experimental study on 10 T-6 and 10 L-4 vertebral bodies from adolescent spines was carried out. The vertebrae were placed on a fixture allowing three-dimensional movements; H and W were

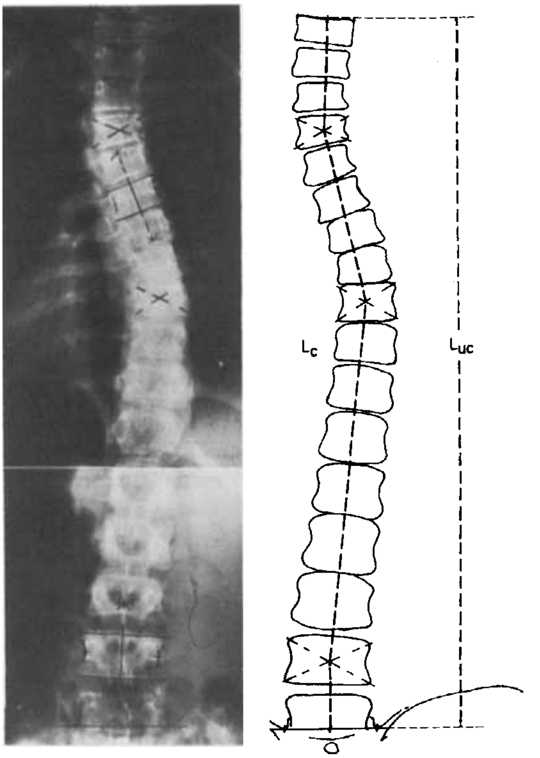

Figure 1. Linear measurements. On this particular X-ray T-6 and L-4 could both be measured (see details in text). The technique for measurement of uncorrected (L_{uc}) and corrected (L_c) length is shown on the drawing.

measured on the screen of a radiographic image intensifier.

The results of this study showed that the vertebral rotation needed to affect the observed lateral diameter (W) always appeared as rotation on the screen. Three-dimensional movements within physiological limits never resulted in an error of the measured dimension by more than ± 5 per cent.

Differences in magnification due to variations in the object-to-film distance is another possible error in these kinds of measurements. The main reason for such variations may be the varying degrees of kyphosis and lordosis, but a rib hump in the IS patients could also be responsible for differences in this respect.

In a study to investigate this effect the maximum difference in magnification was found to be less than 0.7 and 0.3 per cent for T-6 and L-4, respectively (Table 3).

In a further control study of 30 X-rays the reproducibility of the measuring methods was estimated by repeating the measurements of L_c and L_{uc} three times in addition to the initial reading and with approximately 2 weeks delay between each. The expected error in each linear measurement was defined as $\sqrt{\Sigma \frac{(a-a_n)^2}{3n}}$ (n =

Table 3. The effect of variations in object-to-film distance (D) on the radiographic magnification of T-6 and L-4

Number of radiograms	Mean chr. age	T–6 D (cm)	T–6 Percentage magnification difference IS>C	L–4 D (cm)	L–4 Percentage magnification difference IS<C
IS 20	13.71±1.55	8.46±0.91	0.61	14.97±1.67	0.22
C 20	13.70±2.10	7.59±0.75		15.27±1.55	

number of control measurements; a and a_n = initial and repeat readings of the linear measurements). If the expected error was expressed as a percentage of the smallest measurement, the greatest expected error was calculated to be 0.3 and 0.2 for L_c and L_{uc}, respectively. The corresponding values for H and W of T-6 and L-4 (for sample sizes 14 and 12) were 1.9, 1.4, 2.3 and 0.6 per cent, respectively.

An analysis of X-ray films from 407 girls and 79 boys showed the mean chronological ages to be so different (1.3 years for girls) between IS group and controls that a direct comparison of linear measurements was not possible. It was therefore necessary to select samples from the material which had matched mean age. This was accomplished using random deletion from the tails of the age histograms. Since the T-6 and L-4 dimensions could only be measured on parts of the material, the mean ages of each of these samples had to be matched in addition to the total groups for comparison of spinal length ("L groups"). The samples used for comparison of vertebral body dimensions were called "T-6 groups" and "L-4 groups", respectively. A difference in mean chronological age of 0.2 years between IS groups and controls was accepted. In order to investigate if the differences between IS and C groups were age-dependent the female material was divided into age groups below and above 13 years.

The measurement L_c (Figure 1) slightly underestimates the true length of the radiographic image of the thoracolumbar spine. In a control study of 30 X-ray films with Cobb angles from 12 to 40 degrees, the mean percentage underestimation was found to be 0.15 ± 0.25 (0.6 ± 1.1 mm).

RESULTS

Neither the uncorrected nor the corrected length of the thoracolumbar spine was found to be significantly different between IS girls and controls in the age-matched groups. The mean spinal length was slightly larger in the scoliotics (4 mm or 1.0 per cent) (Table 4). After matching the groups according to skeletal age the difference was even smaller. When the different age groups were considered, no significant difference in spinal length could be demonstrated whether under or over 13 years of age. When the measured length of the scoliotic spines was corrected by the method described by Bjure et al. (1968) a significantly longer spine could be demonstrated in the IS group ($P = 0.007$).

After division of the total female material into age groups as shown in Figure 2, no significant difference in spinal length could be found at any age. However, when calculating the age-related change in spinal length it appeared that the pubertal period of accelerated spinal growth started earlier in the scoliotic girls (Figure 3). The IS girls had their maximum gain in spinal length from age group 11 to age group 12 years whereas the controls reached their peak length-gain about 1 year later, from age group 12 to age group 13 years. There was no difference in maximum growth rate between the two groups but the IS girls had a non-significant higher growth rate during the years of late puberty.

The height of T-6 was found to be significantly greater in the IS patients than in the controls in the total sample of age-matched girls ($P = 0.02$) as well as in girls under 13 years of age ($P < 0.02$) (Table 5). In girls over 13 years the difference was no longer significant. The width of T-6 was significantly greater in the youngest group ($P < 0.05$) but not so for the total T-6 groups; in girls over 13 years of age there was no difference at all. In the total T-6 groups there was a more pronounced difference in L_c than could be found in the L groups. In particular for girls under 13 years the scoliotic spine was longer (13 mm or 3.4

Table 4. Uncorrected (L_{uc}) and corrected (L_c) length of the thoracolumbar spine in different samples of age-matched girls. In this and the following tables age and linear measurements are given as the mean ± standard deviation, units are "years" and "cm", respectively

	IS	C	Percentage difference between means	Significance test
Total sample of girls:				
N	154	150		
Chr. age	12.9±2.5	12.7±2.5	1.6	N.S.
L_{uc}	40.7±4.3	40.9±4.2	0.5	N.S.
L_c	41.3±4.4	40.9±4.2	1.0	N.S.
Girls with the same skeletal age:				
N	146	83		
Skel. age	12.2±2.4	12.2±2.3	0	N.S.
Chr. age	12.6±2.3	12.4±2.3	1.6	N.S.
L_c	40.7±4.3	40.5±4.1	0.5	N.S.
Girls ≤ 13 years (chr.):				
N	73	81		
Chr. age	10.8±1.7	10.8±1.6	0	N.S.
L_c	37.8±3.5	37.8±3.2	0	N.S.
Girls > 13 years (chr.):				
N	86	69		
Chr. age	14.9±1.1	14.9±1.2	0	N.S.
L_c	44.5±2.3	44.3±2.1	0.5	N.S.

per cent) although still not statistically significant. The height and width of L-4 were not found to be significantly different in the IS group compared to the controls although H was 2.3 per cent larger in the IS girls.

The samples of boys (IS: C) had to be reduced from 39:40 to 32:33 in order to match their chronological ages. L_c was found to be 12 mm longer in the boys; this is not a significant difference (Table 6). The heights of T-6 and L-4 were greater among the scoliotics whereas the width of both vertebrae was smaller in the scoliotics, all differences being statistically non-significant.

The index H/W was calculated for all T-6 and

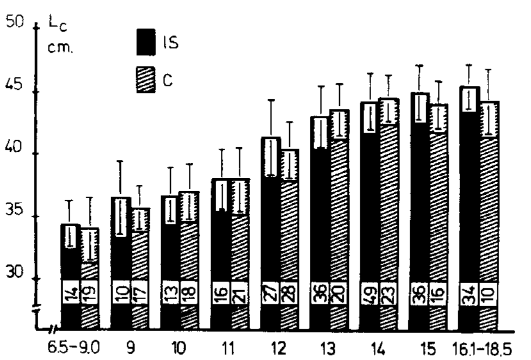

Figure 2. Length of the thoraco-lumbar spine (mean ± standard deviation) in girls of different age groups. Sample sizes are indicated in each column. (9 years ≡ 9.1 – 10.0 years; 10 years ≡ 10.1 – 11.0 years; . . .).

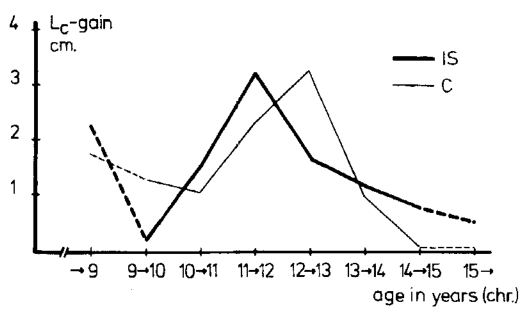

Figure 3. Spinal growth in girls. The figure is based on the same data as Figure 2 and illustrates the gain in mean length of the thoraco-lumbar spine from one age group to the next. The curves indicate annual growth but as the youngest and oldest age groups span 2½ years, dashed lines have been used.

Table 5. Height (H) and width (W) of T-6 and L-4 in different samples of age-matched girls and corrected length of the spine for the same samples

	IS	C	Percentage difference between means	Significance test
Total sample of girls (T-6):				
N	78	78		
Chr. age	13.6 ±2.2	13.4 ±2.5	1.5	N.S.
Height	1.87±0.25	1.77±0.25	5.1	P=0.021
Width	2.52±0.19	2.48±0.20	1.6	N.S.
L_c	42.7 ±3.9	41.8 ±4.1	2.2	N.S.
H/W	0.74	0.71	4.2	
Girls ≤ 13 years (chr.) (T-6):				
N	25	30		
Chr. age	11.0 ±1.8	10.8 ±1.6	1.9	N.S.
Height	1.66±0.19	1.54±0.17	7.8	P=0.017
Width	2.48±0.16	2.38±0.19	4.2	P=0.039
L_c	39.1 ±3.8	37.8 ±3.5	3.4	N.S.
H/W	0.67	0.65	3.1	
Girls > 13 years (chr.) (T-6):				
N	53	48		
Chr. age	14.9 ±1.0	15.1 ±1.2	1.3	N.S.
Height	1.96±0.17	1.92±0.17	2.1	N.S.
Width	2.54±0.20	2.54±0.18	0	N.S.
L_c	44.4 ±2.5	44.3 ±2.1	0.2	N.S.
H/W	0.77	0.76	1.3	
Total sample of girls (L-4):				
N	67	69		
Chr. age	13.9 ±1.9	13.7 ±1.9	1.5	N.S.
Height	2.71±0.36	2.65±0.37	2.3	N.S.
Width	4.33±0.34	4.31±0.34	0.5	N.S.
L_c	43.0 ±3.8	42.5 ±3.7	1.2	
H/W	0.63	0.61	3.3	

L-4 groups and a higher value could be demonstrated in the scoliotics for all test groups and for both vertebral bodies.

DISCUSSION

In the present study no significant difference in the length of the thoracolumbar spine could be demonstrated between IS patients and controls. There was, however, a tendency towards longer spines in the scoliotic children and the significantly greater height of T-6 suggests that one part of the spine (i.e. the thoracic spine) is longer in IS children than in non-scoliotic controls. It does not seem reasonable that the sample used for T-6 measurements should represent a special type of scoliosis patient. The greater percentage difference in the height of T-6 than the difference in spinal length indicates that the increased height of the thoracic vertebra is not merely a consequence of a general increase in spinal length, but could rather be an expression of different growth patterns from one part of the spine to another.

When using the data from Taylor (1973) the calculated relative height-gain in a thoracic vertebral body is markedly greater than in a lumbar one during early adolescent years. Between the ages 10 and 12 years the relative height-gain of T-8 and L-4 in females was 12 and 6 per cent, respectively. When boys and girls were grouped together the height-gain between 10 and 13.5 years was 30 and 21 per cent for the same ver-

Table 6. Corrected length (L_c) of the thoracolumbar spine and the height (H) and width (W) of T-6 and L-4 in age-matched boys

	IS	C	Percentage difference between means	Significance test
Corrected length:				
N	32	33		
Chr. age	13.0 ±2.9	12.8±2.4	1.6	N.S.
L_c	41.9 ±5.9	40.7±4.4	3.0	N.S.
Dimensions of T-6:				
N	7	10		
Chr. age	14.9 ±1.9	14.8 ±2.1	0.6	N.S.
Height	2.01±0.28	1.84±0.26	9.2	N.S.
Width	2.74±0.31	2.80±0.24	2.1*	N.S.
H/W	0.73	0.66	10.6	
Dimensions of L-4:				
N	16	31		
Chr. age	12.7 ±3.1	12.9 ±2.3	1.5	N.S.
Height	2.43±0.51	2.34±0.38	3.8	N.S.
Width	4.54±0.51	4.59±0.38	1.1*	
H/W	0.54	0.51	5.9	

*In these cases the values for IS were smaller than those for the controls.

tebral bodies. Thus, during growth in early adolescence, a greater increase in height of a mid thoracic vertebral body than in a lumbar one is to be expected.

In a study of minifilms Skogland & Miller (1978) found that the incidence of scoliosis among Lapps, who are of small stature (Schreiner 1929), was much lower than in the general population of Northern Norway, 0.5 and 1.3 per cent, respectively. In addition to Willner (1972), Burwell & Dangerfield (1977) and Leong et al. (1977) have reported a greater stature among IS patients than healthy controls. Willner demonstrated a significant difference in sitting height, but only after correction for height loss due to the scoliosis (Bjure et al. 1968). When using the same method in the present material, the mean corrected length of the spine in 235 IS girls became 8.5 mm longer than by measuring along the curvature as described above. The correction method of Bjure et al. seems to overestimate the real length of the spine and may not be valid for curves under 30 degrees (Cobb), since they had no patients with such mild curves in their material. The underestimation of spinal length by a mean of 0.15 per cent in this study should be of negligible practical importance. Nonetheless, the present findings indicate a tendency towards longer spines in IS children and in particular a longer thoracic spine. The increased height of T-6 has to be a consequence of an accelerated growth. Generally, the increase in height of vertebral bodies is the result of enchondral growth at the upper and lower growth plate (Bick & Copel 1950, Knutsson 1961, Gooding & Neuheuser 1965) whereas the increase in width is a result of periosteal growth (Bick 1961). It has been suggested (Neugebauer 1976) that the regulating (hormonal) mechanisms are different for the two types of bone growth, but there is in fact little definite evidence on the "endocrine pathways by which any particular hormone influences skeletal growth" (Sissons 1971).

As shown in Figure 3 the growth of the total thoracolumbar spine is different in the scoliotics compared with the controls, the scoliotic girls having their maximum growth about 1 year earlier than the girls without scoliosis. This finding is in good agreement with Willner's (1972) data and can be explained in terms of changes in hormonal status. The peak growth-rate of the spine in the controls corresponds with the data given by Tupman (1962) and Anderson et al. (1965).

Even before their pubertal growth spurt girls have been found to have a greater absolute height of their vertebral bodies (L-4) than boys and this difference increases with age (Taylor 1973). Brandner (1970) demonstrated that the index of vertebral body height/sagittal diameter was increasingly higher in girls than in boys for body sizes over 90 cm. This index is a measure of the slenderness of the spine and the finding suggests that girls have more slender spines than boys. This difference becomes accentuated during growth.

In the present study H/W, which is another index of spine slenderness, was found to be greater for scoliotics than controls in all the groups studied; this is demonstrated very clearly in the male group (Table 6). In girls over 13 years of age the difference between IS patients and controls was however very small. The data suggest that boys as well as girls with IS have a more slender spine than non-scoliotic controls.

Efforts have been made in the present study to reduce all possible errors. Care has been taken to exclude from the IS groups patients with scoliosis curves which were not idiopathic. By the same token every patient with a possible IS has been excluded from the control groups. In order to avoid problems with secondary skeletal changes, no curve with a Cobb angle over 40 degrees was included. Differences in the posture assumed during the exposure is a source of possible error even if the patients received the same instructions. Changes in posture (i.e. sagittal curvatures) can affect the measured spinal length, increasing the standard deviation and making possible statistical differences harder to demonstrate. The dimensions of the spine proved to be closely related to age and it was therefore necessary to match the mean ages as closely as possible. A difference in mean age of 0.2 years was accepted in order to avoid a too drastic reduction of the sample sizes.

Benson et al. (1976) found that the pedicle-shadow offset, as described by Nash & Moe (1969), was too inaccurate as an indicator of vertebral rotation. Thus, the selection of unrotated vertebrae seemed to be the only safe method if it could be determined how much rotation an "unrotated image" might include. The calculated errors in vertebral dimensions caused by the tilting either in the frontal or in the sagittal plane were found to be acceptable. The values of tilt used in the control study should include all realistic clinical situations.

The errors caused by difference in magnification were found to be within acceptable limits. The most interesting finding, namely the differences in H/W index, is unaffected by possible magnification errors. The increased slenderness of the spine in scoliotics and in particular the difference between scoliotics and controls in boys and in the younger girls makes spine slenderness a factor of possible pathogenetic importance. From a biomechanical point of view this is a very interesting finding, even if the importance still has to be proved. The low slenderness of the normal male spine may be the answer to the question why IS relatively seldom deteriorates in boys; when it progresses the slenderness of the thoracic spine is just as high as in the scoliotic girls (Tables 5 and 6). This increased slenderness-factor might be the reason why the idiopathic curve develops. It is interesting to note that the Lapps with a lower incidence of scoliosis also have a lower equivalent (H/W) lumbar index than other Norwegians (Sand 1970).

No definite conclusions can be drawn as to whether the increased slenderness and the different growth pattern of the spine may be grouped with the primary factors or they are secondary to the scoliosis. However, the hormonal changes previously reported in IS children (Skogland & Miller 1980), which could be linked with changes in growth of this kind, tend to support the former alternative.

CONCLUSION

No statistically significant difference in the length of the thoracolumbar spine between children with idiopathic scoliosis and controls could be demonstrated. In the scoliotic girls, however, it appears that the pubertal growth-spurt of the spine starts earlier and the period of growth lasts longer than in the controls.

A significantly greater height of T-6 in the scoliotic girls suggests a longer thoracic spine in these children. In addition, the higher value of the index height/width of a thoracic as well as a lumbar vertebral body indicates an increased slenderness of the spine in children with idiopathic scoliosis.

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Correspondence to: Lars B. Skogland, Sophies Minde Ortopedisk Hospital, Trondheimsveien 132, Oslo 5, Norway.