Surface Topography and Spinal Deformity

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The rib cage deformity in infantile idiopathic scoliosis -
The funnel-shaped upper chest in relation to specific rotation as a prognostic factor

An evaluation of thoracic shape in progressive scoliosis
and control children during growth

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SUMMARY

This paper reports segmental findings relating to the treatment, prognosis and thoracic shape of 21 children with progressive infantile idiopathic scoliosis (IIS). Thoracic shape was compared with control children.

A new combined surgical procedure derotates the spine, corrects spinal growth and arrests curve progression. In contrast, posterior rodding alone does not prevent the Cobb angle and apical vertebral rotation progressing during follow-up. Conservative treatment was associated with increase of Cobb angle and vertebral rotation.

The upper rib cage in IIS is abnormal as shown by: (a) its funnel shape; (b) rib-vertebra angle (RVA) asymmetry (RVAD) increasing from T1 - T6 and maximum above the apical vertebra; and (c) the vertebral counter-rotation at T4 predicts apical vertebral rotation at follow-up (compare with "specific rotation" of Perdriolle, Vidal 1985).

Thoracic ratios (TRs) and rib-vertebra angles (RVAs) were each measured segmentally (T1 - T12) in the chest radiographs of 412 children aged 0 - 17 years attending hospital with minimal disorder or diseases (boys 193, girls 219). The data were analysed in three age groups - infancy, childhood and puberty, after the classification of Karlberg (1989). The findings show that TRs and RVAs are each related to age, sex and level (of spine and rib respectively). The patterns of RVADs reflects the common age, sex and laterality patterns of idiopathic scoliosis.

Infantile idiopathic scoliosis (IIS) is a structural scoliosis seen in infants, usually boys, with the major curve to the left in almost all cases, and almost invariably in the mid or lower thoracic region. It generally resolves, but in some individuals the curve tends to increase. In the absence of any discoverable aetiology it is termed "idiopathic" and it is believed not to differ in essentials from the more common adolescent scoliosis (James 1951). Subsequently, Scott and Morgan (1955) described resolving infantile idiopathic scoliosis stating that a marked curvature can exist even for several years and then spontaneously resolve. In 1977, Mehta classified idiopathic infantile scoliosis into five categories: resolving, late resolving, benign progressive, malignant progressive and dysplastic (the latter with other clinically recognizable disorders). The frequency of IIS relative to juvenile and adolescent idiopathic scoliosis may be diminishing (McMaster 1983).

The prognosis of IIS is helped by three empirical methods:

1. Rib-vertebra angle difference (RVAD) at the apex of the curve (Mehta 1972).
2. Convex rib-vertebra angle (RVA) at the apex of the curve (Kristmundsdottir et al. 1985).
3. Specific rotation, namely the sum of the two angles of rotation measured in the two vertebrae adjacent to the upper end-vertebra (Perdriolle, Vidal 1985).

The treatment of progressive infantile idiopathic scoliosis generally includes correction by serial
progressive infantile idiopathic scoliosis radiographs (A) preoperative at 4 years, (B) postoperative and (C) at follow-up aged 9 years after combined anterior and posterior (Luque) surgery (Group I).

...plasters (Mehta, Morel 1980, Mehta 1984), a brace and spinal fusion about the age of ten years (McMaster, MacNicol 1979, Hefti, McMaster 1983). In children with double structural curves with less cosmetic deformity McMaster and MacNicol advocate Harrington instrumentation, and posterior spinal fusion for a progressive thoracic curve.

The surface back shape of six boys with progressive IIS treated with Harrington instrumentation and posterior spinal fusion was studied by Dangerfield and Denton (1986). Using the Formulator Body Contour Tracer the rib hump, measured as a trunk asymmetry score (TAS), decreased at the first assessment after surgery, but then increased again in spite of the spinal fusion. Apical vertebral rotation and to a less extent Cobb angle also increased after surgery.

Dangerfield and Denton conclude: "The observation that the TAS increases after Harrington instrumentation is a reflection on the shortcomings of this particular surgical procedure. It appears that spinal fusion does not affect the cosmetic appearance of the rib cage. This implies that it does not affect the underlying progression of the pathology of scoliosis".

Several other surgical methods have been evaluated for the treatment of progressive IIS, the value of each being assessed radiologically (see Winter 1981, Grivas et al. 1990a,b,c). A recent study of children aged 1 - 5 years with progressive IIS shows that a two stage anterior and posterior surgical procedure leads to derotation of the spine during follow-up (Fig. 1, Grivas et al. 1990a,b). This surgical technique developed by
Fig 2 Progressive infantile idiopathic scoliosis. Cobb angle in the three treatment groups (I, II and III) (ARCE = anterior release and convex epiphysodesis).

one of us (J. K. Webb) straightens the spine, permits spinal growth, does not cause posterior tethering of the spine and neurological complications have not occurred. Our findings relating to this combined surgery for IIS have several implications:

(1) As a practical method of treatment for IIS; but it must be emphasised that the findings are preliminary.
(3) The need for quantitative back shape appraisal of treated IIS children throughout growth.
(4) As a study of mechanisms involved in (a) curve progression, (b) curve resolution and (c) prognosis. These implications caused us to undertake a segmental radiological evaluation of the spinal and rib deformity in radiographs of 24 preoperative children with progressive infantile and juvenile idiopathic scoliosis and of 412 control chest radiographs. In this paper, we outline the findings in four parts:

I. The combined surgical procedure for progressive IIS.
II. The funnel-shaped upper chest in progressive IIS.
III. Segmental thoracic ratios of chest width in controls during growth.
IV. Segmental rib-vertebra angles (and RVADs) in controls during growth.

The data reported here provide a background to the study of back shape in these IIS children which we are currently undertaking.

2. THE COMBINED SURGICAL PROCEDURE

2.1 Material

Three groups of patients treated in different ways were studied:

1. Combined epiphysodesis and rodding (n = 9, Group I).
2. Posterior rodding alone (n = 5, Group II).
3. Conservative treatment (n = 7, Group III).

2.1.1 Combined epiphysodesis and rodding (Fig. 1).

Nine patients aged 1 - 8 years (average 3.4 years) each had a two-stage surgical procedure. At the first stage involving a thoracotomy, 4 - 5 discs and vertebral growth-plates were excised on the convexity of the curve and rib autografted (convex epiphysodesis, Roaf, 1955, 1963); at the second stage, Luque rods were attached to the laminae by wires ('Luque trolley') which allows the spine to grow along the rods (Luque, Cardoso 1977).
2.1.2 Posterior rodding alone. Five patients, aged 5 - 9 years (average 7.2 years), had a Luque trolley without anterior surgery.

2.1.3 Conservative treatment. Seven patients aged 1 - 6 years (average 3.2 years) were treated with plaster jackets and/or braces and followed-up for 6.8 years without surgery.

2.2 Methods

2.2.1 Radiographs. The preoperative, postoperative and follow-up radiographs were assessed using the following techniques: Cobb angle and fusion angle (Cobb 1948); end-vertebra angles (Appelgren, Willner 1986, 1990, Wojcik et al. 1989); apical vertebral rotation (Perdriolle 1979); segmental measurements of each of vertebral rotation, a.p. vertebral tilt (Wojcik et al. 1990a,b) and sagittal spinal shape (Kiel et al. 1990, Wythers 1990, Wythers et al. 1990b, Wythers et al. 1992); and rib-vertebra angles (RVAs) on the convexity and concavity from T1 - T12, both uncorrected (Wojcik et al. 1990a,b) and corrected for vertebral tilt (Wythers 1990, Wythers et al. 1990a, 1992). Kyphosis and lordosis angles were measured (Cobb 1948).

In group I, convex and concave fusion distances were measured using a flexible wire contoured to fit the outline of the vertebræ on the a.p. radiographs namely, as the distance from the upper corner at each upper vertebral body to the lower corner of the lower vertebral body on each of the convexity and concavity of the fusion angle. In order to correct these lengths for magnification, a ratio was calculated using as denominator the distance from T1 - T12 on a.p. radiographs after correcting for loss of height due to the lateral spinal curvature using the formula of Hodgett et al. (1986, log y = 0.683 + 0.014x, where y = calculated trunk height loss in mm and x = Cobb angle). These convex and concave ratios were calculated for preoperative, postoperative and follow-up films.

2.2.2 Statistical analysis. Statistical techniques included Wilcoxon, Mann-Whitney, Kruskal-Wallis, Spearman correlation coefficient and multiple linear regression analysis.

2.3 Findings

No neurological complications occurred.

2.3.1 The fate of the spinal curves in Groups I, II and III.

Group I (Fig. 2 - 4). After surgery, the Cobb angle corrected from 58° to 21° (p = 0.008) and the apical vertebral rotation from 33° to 24° (p = 0.02). At follow-up (mean 3.4 years, range 1.3 - 4.5 years), the Cobb angle was 22° and apical vertebral rotation decreased to 15° (p = 0.008).

Group II. After surgery, the Cobb angle reduced
Group III. During treatment, the Cobb angle increased from $50^\circ$ to $69^\circ$ and the apical vertebral rotation from $32^\circ$ to $37^\circ$. These increases are significant ($p = 0.02$ and $p = 0.03$ respectively).

2.3.2 Spinal growth. In Group I, during the period of study (preoperative to follow-up), the convexity maintained its proportion to the corrected length of the thoracic spine. In contrast, the concavity increased its proportion to the thoracic spinal length between the preoperative and follow-up films. These findings imply that the fused segment of the spine is still growing and with significantly greater growth (7%) on the concavity compared with the convexity of the fused spinal segment.

2.3.3 Rib-vertebra angle differences (RVADs). The RVADs early in management were plotted by rib level for all groups combined. The maximum RVAD of $50^\circ$ occurs at T6 above the level of the apical vertebra. Further details related to the rib-vertebra angles are given elsewhere (Grivas et al. 1990g).

2.3.4 Back shape. Subjectively, the back shape of these children is improving and is currently being evaluated using our back appraisal systems (Burwell et al. 1992a, Burwell and Dangerfield 1991).

2.4 Discussion

In the patients having combined anterior and posterior surgery, the Cobb angle was corrected and maintained during the period of follow-up (Fig. 2). Moreover, the apical vertebral rotation which improved significantly after surgery, diminished further in follow-up (Fig. 3). These changes in vertebral rotation are best shown in the segmental plot of vertebral rotation (Fig. 4).

In group II, the Cobb angle improved significantly after posterior rodding but deteriorated during follow-up. The apical vertebral rotation was not changed significantly by surgery or in follow-up. In the segmental plot of vertebral rotation, little or no changes are revealed.

In group III, the deformity measured as Cobb angle, apical vertebral rotation, segmental vertebral rotation and segmental a.p. vertebral tilt increased despite treatment.

2.4.1 A possible mechanism leading to resolution of the group I curves - growth correction rather than epiphysodesis. The beneficial effects of combined surgery compared with posterior rodding alone are (1) greater derotation postoperatively and (2) maintained correction of Cobb angle and further derotation during follow-up. The latter derotation is associated with growth in the
"fused" segment which is significantly greater (7%) on the concavity than the convexity. Hence the epiphysodesis and rodding do not cause an arrest of growth but a correction of spinal growth. We suggest that the anterior release and vertebral growth alteration enable the posterior rods to control the frontal and sagittal plane deformities of the scoliosis. In group II, the posterior rods in the presence of an intact anterior column are unable to resist the deforming forces generated in the tissues of the trunk during growth.

2.4.2 The upper thorax in IIS and RVADs. Further evidence that there is an anomaly or defect in the upper thorax of patients with IIS is given in the next section which shows that the rib cage at T1 - T4 in progressive IIS is narrower than in controls (funnel-shaped chest, Grivas et al. 1990d,e). The rib-vertebra angle asymmetry (expressed as RVADs) increases from T1 - T6 and is maximum above the apical vertebra. The prognostic value of RVADs at different rib levels needs evaluation in IIS. It may be that RVADs at T5 - T6 provide a better prognosis than do apical RVADs.

3. THE FUNNEL-SHAPED UPPER CHEST IN PROGRESSIVE INFANTILE IDIOPATHIC SCOLIOSIS (IIS)

It was necessary to develop a new method to measure the segmental shape of the rib cage on radiographs (Grivas et al. 1990e,f). Thoracic ratios were calculated for the right and left hemithorax, dividing the distance from each vertebra to the lateral thoracic border by the T1 - T12 distance (corrected for loss of height due to the lateral spinal curvature, Hodgett et al. 1986, see 2.2.1). Thoracic ratios were also obtained from the chest radiographs of 412 healthy children.

3.1 Material from controls

Posteroanterior (p.a.) chest radiographs were obtained from 412 children aged 0 - 17 years attending the Accident and Emergency Department at the University Hospital, Nottingham during 1989 - 1990. The children had minimal disorders or diseases involving trauma, infections, foreign bodies, heart murmurs and mild asthma. None of the patients had a scoliosis of 5° or more. Two patients with congenital fusion of upper ribs both in a hemithorax were identified. Radiographs which were oblique were excluded. The chest radiographs were usually obtained in full inspiration. The age of each subject was calculated as decimal age. All the 233 control children aged 1 - 9 years were used in the comparison with the scoliotic patients. The mean age was 5.049 ± 2.592 (S.D.) years (boys 105, girls 128).

3.2 Methods

3.2.1 Measurements on chest radiographs

3.2.1.1 Thoracic ratios. On each chest radiograph, the outline of the lateral border of the thorax is drawn (Fig. 6). Next, the mid-point of the distal end-plate at each vertebral body from T1 - T12 is marked. Then at each segment, the distance from the middle of the end-plate to each outline of the right and left thoracic cage is measured. These distances are standardized by dividing by the measured T1 - T12 distance. They are termed segmental left and right thorac-
ic ratios (TRs). Ratios are also calculated segmentally for the total width of the chest (left plus right measured lengths). In a small number of the chest radiographs the lower two ribs were difficult to define, but in the films selected there were often abdominal and occasionally spinal radiographs to facilitate the measurements. No such problems were found for the spinal radiographs.

3.2.1.2 Scoliotic patients. The a.p. spinal radiographs of 24 children with progressive IS were evaluated using the methods described below. In this group, there were 16 boys and 8 girls. Their mean age was $4.071 \pm 2.658$ (S.D.) years (range 1.065 - 9.068). The mean Cobb angle was $54^\circ$ (range $32^\circ$ - $78^\circ$). None of the patients had received surgical treatment. A few of the patients had been treated with plaster casts and/or brace. Their average age at onset was 2 years; the average interval between onset and the radiological evaluation was 2.82 years.

In follow-up, there were 21 patients who received different treatments, namely: Group I - combined anterior and posterior surgery leading to apical vertebral derotation ($n = 9$, Grivas et al. 1990a,b,c); Group II - posterior rodding alone ($n = 5$, Grivas et al. 1990a,b); and Group III - conservative treatment - brace and/or plaster ($n = 7$, Grivas 1990c).

Fig 6. Method of calculating segmental thoracic ratios on chest radiographs. $DR$ and $DL$ are distances from the middle of an end-plate to the outlines of the thoracic cage, $H$ is the distance from $T1$-$12$ (see text).

Fig 7. Thoracic ratios in controls and in progressive infantile idiopathic scoliosis
B O Y S

Cobb angle was measured after the method of Cobb (1984). Vertebral rotation was measured segmentally after the method of Perdriolle (1979) including apical vertebral rotation. The a.p. vertebral tilt was measured segmentally as the angle which the lower border at each vertebra (T1 - L5) makes with a transverse line drawn at right angles to a vertical line from S1 (Wojcik et al. 1990a,b). Vertebral tilt angles below the transverse line are deemed positive and above negative.

3.2.2.3 Follow-up. At follow-up, apical vertebral rotation was measured for each of 21 patients. The average period of follow-up was 3.4 years for group 1, 5.7 years in group 2 and 6.8 years in group 3.

3.2.2.4 Statistical analysis. The statistical techniques included Wilcoxon, Mann-Whitney, Kruskal-Wallis, Spearman correlation coefficient, multiple linear regression analysis and ANOVA.

3.3 Findings

Due to the complexity of assessing thoracic ratios separately for the left and right hemithorax of scoliotics, we use combined ratios for purposes of comparison. Fig. 7 provides a general indication of the comparison between each hemithorax of the scoliotics and controls.

3.3.1 Thoracic ratios in control subjects. Fig. 8 shows the segmental thoracic ratios for the control boys and girls separately. There is no statistically significant difference between boys and girls at T1 - T7. Below T7 there is a sex difference at T8 - T10 with the girls having narrower chests (relative to length) than boys at these levels (p = 0.05). In view of these findings, the thoracic ratios are pooled for control boys and girls. The comparison of the scoliotics with the controls with the scoliotics is valid for T1 - T7 but not below T7 because the samples of controls

![Thoracic Ratio Diagram](image-url)

Fig 8. Segmental thoracic ratios in control boys and girls

3.2.2 Radiological measurements on the scoliotics' rib cage

3.2.2.1 Thoracic ratios. On a.p. spinal radiographs the outline of the lateral border of the thorax was drawn. The method used to calculate thoracic ratios was similar to that used on the chest radiographs with the exception that the T1 - T12 distance was corrected for loss of height using the formula of Hodgett et al. (1986, see above 2.2.1). They are termed segmental convex and concave thoracic ratios (TRs).

3.2.2.2 Cobb angles and segmental vertebral rotation. At the time of the initial examination, the
3.4Discussion

The funnel-shaped upper thoracic cage of IIS is like that of each: (a) a normal human foetus; (b) asphyxiating thoracic dysplasia (Jeune’s disease, Smith 1978); and (c) a normal adult rabbit (Fig. 9). The finding suggests that there are different patterns of postnatal growth in the upper and lower ribs of the human.

3.4.1 Rotation of T4 in relation to apical vertebral rotation at follow-up. Fig. 5 shows that 29% of the apical vertebral rotation at follow-up is explained by the counter-rotation initially present at T4. By the time of follow-up, various treatments had been used namely, combined anterior and posterior surgery, posterior rodding alone, and conservative treatment. We conclude that treatment is not the only factor contributing to apical vertebral rotation at follow-up. Our findings provide support for the conclusion of Perdriolle and his colleagues that "specific rotation" (the sum of the two angles of rotation measured on the two vertebrae adjacent to the upper end-vertebra) can be used prognostically in IIS (Perdriolle 1979, Perdriolle, Vidal 1985, Perdriolle et al. 1989).
3.4.2 The upper chest in progressive infantile idiopathic scoliosis (IIS). The evidence suggesting that the upper rib cage in IIS is abnormal is as follows:

(1) the upper rib cage is narrow (funnel-shaped);
(2) the RVA asymmetry (RVADs) increases from T1 - T6 and is maximum above the apical vertebra; and
(3) the vertebral counter-rotation at T4 predicts the apical vertebral rotation at follow-up (compare with "specific rotation" of Perdriolle, Vidal 1985).

We suggest that specific rotation (and more specifically the counter-rotation at T4) above the apex of the thoracic curve, reflects the impaired rib control of spinal rotation caused by the growth defect in the upper rib cage. Neuro-muscular factors are likely to determine the primary thoracic curve of IIS and, if more widespread in paraspinal muscles, the upper rib cage defect (funnelling) leading to a progressive deformity.

3.4.3 Congenital rib fusions, scoliosis and hemifunnelling. Congenital rib fusions of an upper hemithorax (hemifunnelling) are associated with a scoliosis curve below the last level of the rib fusion, convex to the side of the rib defect (Grivas et al. 1990d,e).

3.4.4 Segmental radiological patterns. The segmental radiological patterns of the spine and rib cage deformity of progressive IIS are similar to those of patients with progressive thoracic adolescent idiopathic scoliosis (AIS) (Wythers 1990) with the exception of the lumbar spine; the IIS patients show (a) less intervertebral rotation and (b) less a.p. intervertebral tilt at each motion segment than do the adolescents.

4. THORACIC RATIOS IN CONTROLS DURING GROWTH

4.1 Material

The posteroanterior (p.a.) chest radiographs were obtained from 412 children attending the Accident and Emergency Department at the University Hospital, Nottingham during the 1989 - 1990 (see above 3.1).

4.1.1 Age and sex groups. The subjects were arranged into three age groups by sex in accordance with the classification of Karlberg (1989) (infancy = 0 - 2.999 years, boys = 37, girls = 54; childhood = 3 - 10.999 years, boys = 96, girls = 102; and puberty = 11 - 17.999 years, boys = 60, girls = 63).

4.2 Measurements on chest radiographs

4.2.1 Thoracic ratios. The method is described above (3.2.1.1).

4.3 Findings

4.3.1 Thoracic ratios (TRs). Fig. 8 shows the thoracic ratios by level for left and right hemithorax for each of boys and girls in the three age groups (infancy, childhood and puberty). The findings show (Grivas et al. 1990f):

(1) The chest broadens from T1 to about T10 - T11.
(2) Between infancy and childhood, relative to its length the chest narrows from above downwards and particularly in the lower chest (T5 - T12 average diminution, boys 9.5%, girls 9.8%). In the upper chest, the narrowing is more marked in girls than boys (T1 - T4 average diminution, boys 5.1%, girls 8.2%).
(3) Between childhood and puberty, the girl's but not the boy's chest narrows further in its lower half (below T6 average diminution 3.3%). At T6 and above there is no detectable change in the relative width of the chest in either boys or girls.

4.4 Discussion

4.4.1 The ICP model of growth. An important feature of our analysis of thoracic ratios in children from 0 - 17 years is the use of the ICP model of Karlberg (1985, 1989). This model breaks
down growth mathematically into three additive and partly superimposed components - infancy, childhood and puberty. These components strongly reflect the different hormonal phases of the growth process. As a result, the model provides an improved instrument for detecting and understanding growth failure. It has already been applied to Perthes’ disease (Burwell et al. 1986), slipped upper femoral epiphysis (Hagglund et al. 1987) and adolescent idiopathic scoliosis (Hagglund et al. 1990).

4.4.2 The thoracic ratio method. The thoracic ratio method expresses the width of the left and right hemithoraces segmentally in relation to the distance from T1 - T12. It does not express rib length directly but the values are dependent on rib length as measured on the a.p. projections of the chest radiographs. Oblique radiographs were excluded from the series. Subjects with minimal lateral spinal curves (4° or less) were included; such curves could influence the findings, but the effect is likely to be small.

Three major factors which determine the TRs are evidently (a) rib length, (b) thoracic spinal length, and (c) the position of the ribs measured as rib-vertebra angles (Grivas et al. 1990g).

4.4.3 Relation to spinal level and age. Fig. 8 shows the shape of the thorax in the frontal (a.p.) plane as thoracic ratios for the controls. Three features are worthy of comment. Firstly, the broadening of the chest from T1 - T10/11; secondly between infancy and childhood, the chest narrows relative to spinal length from above downwards. Thirdly, between childhood and puberty there is a further narrowing of the girl’s chest in its lower half (T6 - T12). Between childhood and puberty above T6 there is no detectable change in the relative width of the chest in either boys or girls.

4.4.4 Relative narrowing of the chest during growth; an hypothesis involving pelvic and thoracic inertia in gait. The relative diminution of TRs particularly of the lower thorax with increasing age in boys and girls may be a mechanism to reduce the rotational inertia created in the thorax from the rotating thoracolumbar spine and pelvis in gait. Such a mechanism would consume energy. It will be recalled that inertia (I) equals Σ mr², (where Σ = sum, m = mass and r = radius). Hence, a relative diminution of thoracic width would produce a much greater reduction of rotational inertia, because inertia is a function of the square of the distance. In evolutionary terms, the chest narrowing is consistent with an adaptation of the human rib cage to bipedal gait (see Burwell et al. 1992b).

5. SEGMENTAL RIB-VERTEBRA ANGLES IN CONTROLS DURING GROWTH

5.1 Material

See 4.1.

5.2 Methods

5.2.1 Measurements on chest radiographs

5.2.1.1 Rib-vertebra angles (Fig. 10). The rib-vertebra angles (RVAs) were measured in each of the right and left hemithorax from T1 - T12.

Fig 10. Method of measuring segmental rib-vertebra angles (RVAs) on chest radiographs
Fig 11. Segmental rib-vertebra angles (RVAs) in control boys and girls (mean ± ISE). Junctional ribs are indicated by large stars (*).

(Meha 1972, Kristmundsdottir et al. 1985, Wojcik et al. 1990a,b, Wythers 1990 Wythers et al. 1990a,b, 1992). The techniques used previously were modified slightly because of two factors: (1) the head of the rib is not as clearly evident in older children as it is in infants; and (2) the upper ribs curve upwards and laterally from the spine. The modifications involve new methods to measure RVAs, the details of which are discussed elsewhere (Grivas et al. 1990g).

5.2.1.2 Rib-vertebra angle asymmetry (RVAD). A derivative, usually referred to as the rib-vertebra angle difference (RVAD) is calculated for each segment as left RVA minus right RVA.

5.2.2 Statistical analysis. Statistical techniques included Wilcoxon, Mann-Whitney, Kruskal-Wallis, Pearson and Spearman correlation coefficients, ANOVA, cross-tabulations, t test for asymmetry, and tests for skewness and kurtosis including the one-sample Kolmogorov-Smirnov test (Snedecor, Cochran 1980).

5.3 Findings

5.3.1 Rib-vertebra angles (RVAs). Fig. 11 shows RVAs by rib level for left and right hemithorax and for each of boys and girls at the three age groups (infancy, childhood and puberty).

The findings show (Grivas et al. 1990g):

(1) RVAs droop increasingly from T1 - T12 and especially at T8 - T12.

(2) Between infancy and childhood the upper ribs elevate which is greater and evident at more levels in boys than girls.

(3) Between childhood and adolescence there is a further elevation of ribs, again more extensive in boys than girls (boys T1 - T10, girls T1 - T8).

(4) Junctional ribs droop early in growth and elevate later.

(5) In the lower chest between infancy and childhood, the ribs droop more in girls than boys (boys T9 - T10/12, girls T7/8 - T12). Between childhood and puberty, the lower RVAs show no further droop in boys and girls.
5.3.2 Rib-vertebra angle differences (RVADs). Fig. 12 shows the RVADs plotted against age for each age group. A weak asymmetry is seen in infancy boys at T8. Infant girls show asymmetry at two levels (T4 - T5); girls in childhood show significant asymmetry at T6 - T7 and adolescent girls at T4 - T7. The childhood and adolescent boys show little or no significant asymmetry.

Comparing infancy with childhood, the boys show a significant lessening of the droop of the left ribs (relative to those on the right) at each of 5 levels (T5 - T9). The girls show little or no change in RVADs between infancy and childhood. Comparing childhood with adolescence, the boys show no change in RVADs; but the girls show increasing droop of right ribs (relative to those on the left) at each of 2 levels (T3 - T4).

5.4 Discussion

5.4.1 Possible factors causing the age-related changes in RVAs-muscular mechanisms. In growing healthy subjects, RVAs will be influenced by muscles attached to the ribs. Some back muscles exert their pulls in a superior or an inferior direction (see Carey, 1932). We suggest the hypothesis that the angle which a rib makes with its vertebra is, in part, the resultant of summated muscular forces acting continually in opposite directions along the length of the growing trunk i.e. RVAs express muscle balance.

According to this muscular hypothesis, the elevation of upper ribs during growth results from relatively more powerful cranial than caudal muscles attached to ribs. Conversely, drooping of lower ribs during growth results from relatively more powerful caudal muscles. This concept implies that there is a physiological alteration of muscle balance on ribs during growth due to developmental changes in the central nervous system. The more extensive rib elevation in boys is consistent with the favouring of the shoulder girdle in males. More powerful cranial muscles in males would explain why the adult male manubrium is positioned at a higher level than that of females (Williams, Warwick 1980, see Grivas et al. 1990g).

5.4.2 Side differences - rib-vertebra angle asymmetry. The RVAD findings show significantly more drooping left RVAs (relative to right RVAs) at T8 in infant boys. In childhood and puberty the boys show little or no RVA asymmetry. In contrast, the RVAs in girls are significantly asymmetrical in infancy (T4 - T5), in childhood (T6 - T7) and markedly so in puberty (T4 - T7, Fig. 12); their RVAs droop more on the right (relative to those on the left) in each of
Using the muscular hypothesis already mentioned, we suggest that "normal" RVA asymmetry results from an alteration of physiological balance between cranial and caudal muscles attached to ribs on one side (or asymmetrically on both sides) of the chest. The pattern of RVADs reflects the common age, sex and laterality patterns of idiopathic scoliosis. We suggest that extremes of such asymmetries are aetiological for infantile, juvenile and adolescent idiopathic scoliosis.

6. THE RIB CAGE IN CONTROLS DURING GROWTH

The segmental evaluation by each of thoracic ratios and rib-vertebra angles on chest radiographs from control children during growth shows:

(1) A narrowing of the chest relative to length during growth.
(2) Upper rib-vertebra angles elevate during growth.
(3) Junctional ribs droop early in growth and elevate later.
(4) Lower rib-vertebra angles droop during growth.
(5) The rib-vertebra angle asymmetries (RVADs) shows patterns related to the patterns of idiopathic scoliosis in age, sex and laterality.

7. CONCLUSIONS

(1) A combined surgical procedure for progressive IIS is outlined. It has implications for the pathogenesis of scoliosis.
(2) Back shape appraisal of children with IIS is needed.
(3) The upper chest in progressive IIS is abnormal and features of it relate to prognosis, and possibly to pathogenesis.
(4) The segmental radiological patterns of the spine and rib cage deformity of progressive IIS are similar to those of patients with progressive thoracic adolescent idiopathic scoliosis (AIS, Wythers 1990, Wythers et al. 1990b, 1992), with the exception of the lumbar spine; the IIS patients show (a) less intervertebral rotation and (b) less a.p. intervertebral tilt at each motion segment than do the adolescents.
(5) Segmental thoracic ratios from chest radiographs of control children reveal narrowing (relative to spinal length), especially of the lower rib cage during growth, particularly in girls.
(6) Segmental rib-vertebra angles of chest radiographs from control children reveal age and sex-related changes during growth which occur in upper (elevation) or lower (drooping) ribs. Junctional ribs droop early in growth and elevate later.
(7) There are patterns of rib-vertebra angle asymmetry (RVAD) during "normal" growth which are akin to idiopathic scoliosis (see Burwell et al. 1992b).

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REFERENCES

Appelgren, G., Willner, S. (1990), End-vertebra
Arrest of curve progression by epiphyseodesis and rodding for early onset scoliosis,
Clinical Anatomy 3, 24

Grivas, T.B., Webb, J.K., Burwell, R.G. (1990b),


Kristmundsdottir, F., Burwell, R.G., James, J.I.P., (1985), The rib-vertebra angles on the convexity and concavity of the spinal curve in infantile idiopathic scoliosis, Clinical Orthopaedics 201, 205-209

Luque, E.R., Cardoso, A. (1977), Treatment of scoliosis without arthrodesis or external support, preliminary report, Orthopedic Transactions 1, 37, 37


McMaster, M.J., MacNicol, M.F. (1979), The management of progressive infantile idiopathic scoliosis, J. Bone Joint Surg. 61B, 36-42

Mehta, M. (1972), The rib-vertebra angle in the early diagnosis between resolving and progressive infantile scoliosis, J. Bone Joint Surg. 54B, 230-243


Perdriolle, R. (1979), La scoliose, son étude tridimensionnelle, Maloine S A Editeur, 27 Rue de l’Ecole-de-Médecine, 75006 Paris


Webb, J.K. (1990), Personal communication


Wythers, D.J. (1990), A segmental analysis of factors predicting deformity in adolescent
idiopathic scoliosis, The relevance of the lumbar spine to aetiology, Thesis: University of Nottingham

