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Nuffield Orthopaedic Centre, Oxford, England.

A NEW PROJECTIONAL LOOK AT ARTICULATED SCOLIOTIC SPINES

GRAHAM DEANE & ROBERT B. DUTHIE

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Anatomical analyses of scoliotic spines present considerable difficulties, and the voluminous literature only indicates the complexity of the subject rather than its solution. Clinical research based upon standard radiography has helped in understanding aetiology and epidemiology, classification, and differentiation of the types, as well as the various patterns of deterioration. However, the actual structural deformity and its mechanism of development still remains obscure. The source of such information is to be found in articulated macerated specimens of complete but scoliotic spines. Obviously one is only studying the deformity of bones and their articulations, without the all important supporting structures of muscles, ligaments, and in some cases, the thoracic cage and pelvis. Even so, this type of material, which is very rare because of the loss, during the War, of Schmorl's collection in Dresden and the Hunterian collection at the Royal College of Surgeons of England, has been discovered in the museum of the Royal College of Surgeons, Edinburgh. Single specimens have been submitted to mensuration, dissection and usual radiography by Roaf (1971) who described how the structural rotation was associated with increase in the length of the anterior vertebrae with an excessive growth of the articular processes and laminae. Langenskiöld (1971) has also observed the abnormal growth of the posterior elements in experimental scoliosis of the rabbit. The biomechanical stabilizing effect upon axial rotation of the posterior element, e.g. facet joints, laminae and ligaments, has been described by White & Hirsch (1971) from their experiments in cadaveric thoracic spines.

Results from studies of five articulated scoliotic spines by a new projectional method for rotation, for linear relationship of the vertebral bodies to their posterior elements, and for changes in the compensatory curves will now be presented.

Table 1.

	Specimen	Primary curve	Direction of curve	Vert. body distortion	Facets
1	Spine alone	T6–L1 inclusive rotational lordosis	Convex to right	Moderate	Symmetrical
2	Spine and pelvis	T7–L1 inclusive kyphoscoliosis	Convex to right	Considerable	Assymmetrical at apex of curve.
3	Spine and pelvis	T4-T12 inclusive kyphoscoliosis	Convex to right	Mild	Symmetrical
4	Spine, pelvis and rib cage	T3–T9 inclusive kyphoscoliosis	Convex to right	Moderate	Symmetrical
5	Spine and rib cage (child)	T4-T12 inclusive kyphoscoliosis	Convex to right	Moderate	Some fusion on Lt. side T7–T10

MATERIALS AND METHODS

Five dry macerated but articulated specimens of structural scoliotic curves have been examined by courtesy of Professor D. E. C. Mekie, Conservator of the Museum, Royal College of Surgeons, Edinburgh (Table 1). They were selected both by history and by physical examination to exclude such obvious osseous pathologies as rickets, congenitally abnormal vertebrae, and following thoracoplasty. The type of "primary" scoliosis studied here, with its primary curve and compensatory curves, helped to differentiate these from the scolioses resulting from the neuro or myopathic diseases of poliomyelitis or muscular dystrophy. Even so the term 'idiopathic' has purposely not been used here as it was clearly recognised that these specimens were old and therefore difficult to differentiate whether the bony and articular changes were primary or secondary. The examination took two general forms: (1) linear surface measurements and (2) radiographic analysis.

(1) *Linear surface measurements* of individual anterior vertebral body length from T1 to L5 were made by tape and compared to those from three other dry anatomical specimens of normal but articulated spines.

Further linear measurements were carried out for the total overall length of the articulated specimens, both anteriorly along the vertebral bodies and posteriorly along the spinous processes. (Comparison was made between these and of the absolute lengths of the normal articulated dry spines.) In addition the anterior and posterior lengths of the primary curve, and of the compensatory curves above and below, were obtained.

(2) *Radiographs* were made of the mounted specimens in the standard scoliosis views—antero-posterior (coronal plane) and lateral (sagittal plane). "Non standard" radiographs from above were made to give horizontal or transverse axial sections at various levels of the spinal curves. Vertebral rotation was measured by

means of this serial linear tomography. All radiographs were taken with the specimens both marked and unmarked. In the marked series, lead "strips" were attached to the vertebral bodies anteriorly, and lead "diamonds" attached to the tips of the spinous processes. A flexible rod was introduced along the spinal canal in two spines without damaging the specimens, but in two this was not possible, and in the fifth a rod was already in place.

RESULTS

Linear surface measurements

The individual anterior vertebral body lengths for the normal and scoliotic spines have been made non-dimensional for comparison and are represented in the following graphs:

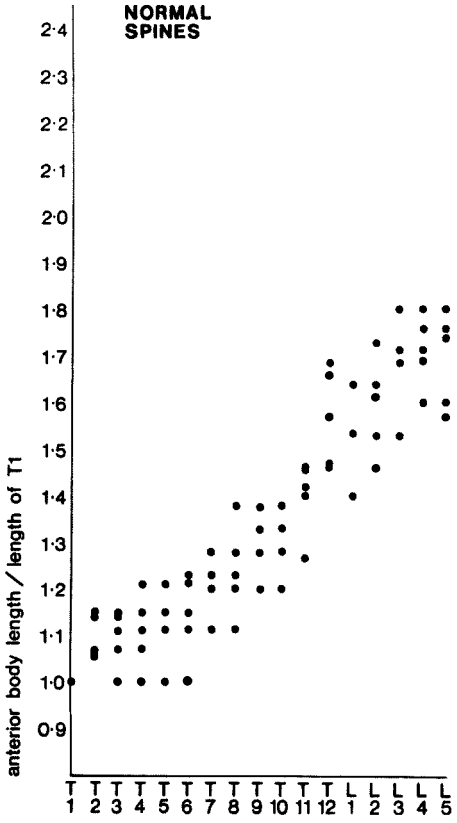


Figure 1. Normal spines. Individual anterior vertebral body lengths expressed as a ratio of the length of T1.

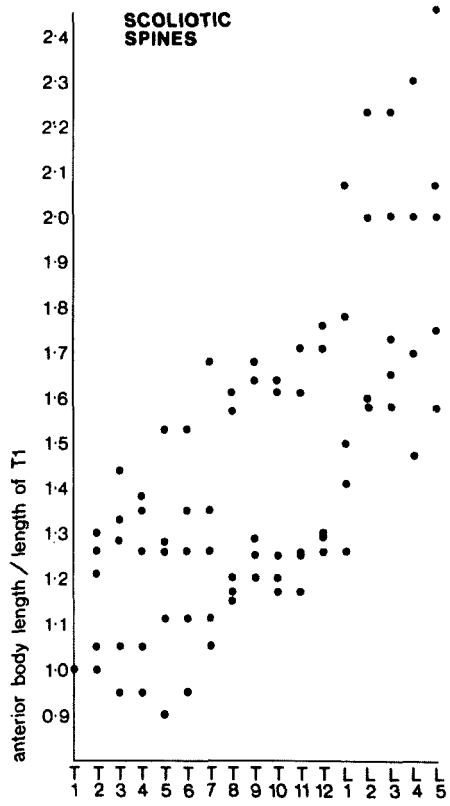


Figure 2. Scoliotic spines. Individual anterior vertebral body lengths expressed as a ratio of the length of T1.

This showed that the length of the vertebral bodies, as expected, became longer as one progressed down the vertebral column, from upper thoracic to lower lumbar. The slope of the graphs showed that this occurred at an equal rate both in the normal and scoliotic spines.

The total linear measurements of both the normal and scoliotic spines are shown in Table 2. It was found that the length of the normal anterior vertebral bodies, i.e. 450 mm on average, was almost the same as the length of the scoliotic vertebral bodies, i.e. 447 mm on average (Table 2). However, the posterior length in the normal spines was on average 446 mm, i.e. similar to the anterior lengths, but in the scoliotic spine there was significant reduction in length to 397 mm on average. The lengths of the individual primary and compensatory curves in the scoliotic specimens are presented in Tables 3 and 4. Measurement of the primary curves demonstrated a kyphosis in four specimens and a lordosis in one (Table 3). The compensatory curves were measured

Table 2. Total length of thoraco-lumbar spine (mm) measured along veterbral bodies (anterior) and spinous processes (posterior).

		Anterior (mm)		Posterior (mm)	
Normal	1	440		450	
	2	415		420	
	3	495		470	
		Average length	450 mm	Average length	446 mm
Scoliotic	1	445		330	
	2	435		405	
	3	470		430	
	4	440		425	
	5*	390		320	
		Average length	447 mm	Average length	397 mm

* This specimen was from a child and therefore not included in the averages of the adult spines.

Table 3. Anterior and posterior lengths of primary curves.

	Extent of curve	Anterior (mm)	Posterior (mm)
1	T6–L1	110	77
2	T7–L1	195	205
3	T4–T12	220	230
4	T3–T9	150	185
5	T4–T12	190	195

Table 4. Added anterior and posterior lengths of compensatory curves (above & below)

	Anterior (mm)	Posterior (mm)
1	235	253
2	240	200
3	250	200
4	290	240
5	200	125

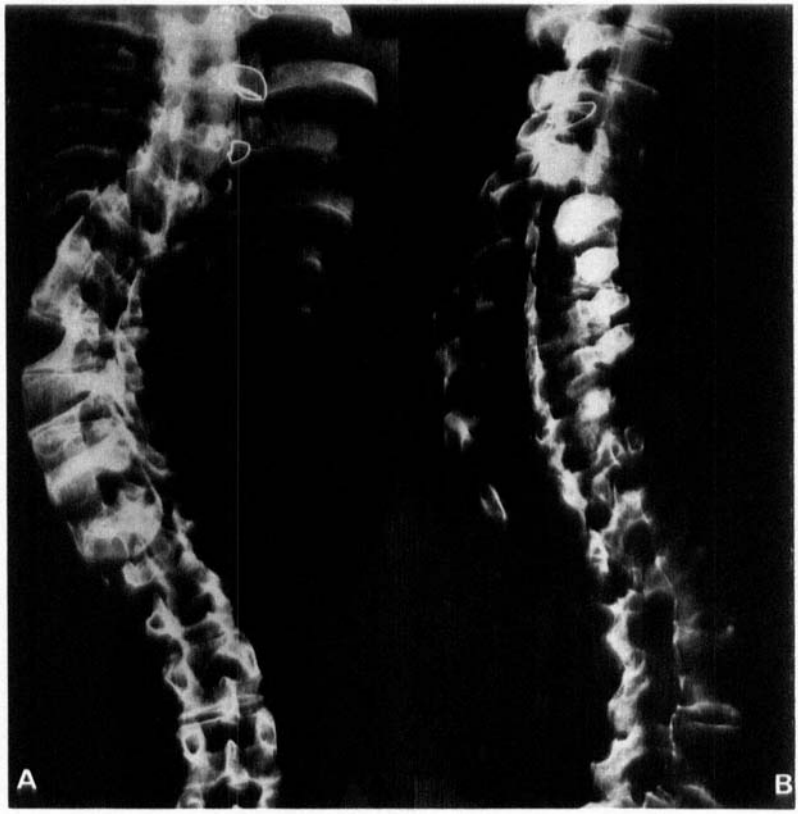


Figure 3. a. Standard antero-posterior radiograph of specimen 1. – b. Standard lateral radiograph of specimen 1.

(Table 4) and showed that where there was a kyphosis, i.e. specimens 2, 3, 4, and 5, there was a compensatory lordosis. On the contrary where there was a lordosis in specimen 1—the compensatory curves were kyphotic.

Radiographic analysis

The results for specimen 1 are fully illustrated (Figures 3–9) and are a typical example.

The results of the radiographic measurements in all the specimens are given in Table 5, with additional notes on other findings. The finding common to all specimens was the relatively small deviation from the midline of the spinous processes (Figures 5 and 6), and the

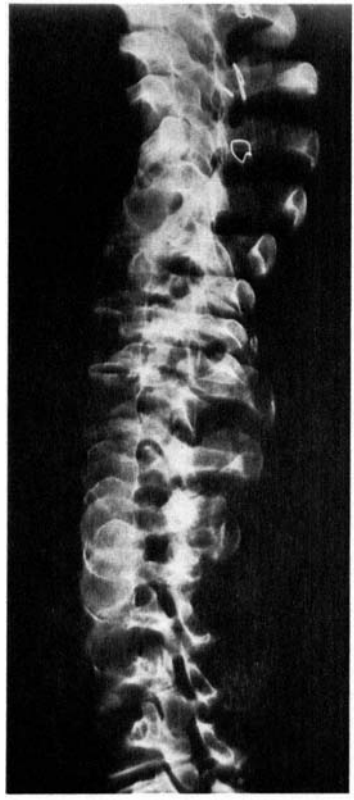


Figure 4. Obligue radiograph of specimen 1 showing that positioning of the spine relative to x-ray projection concealed the true severity of the curve measured in the standard way.

greatest rotatory distortion was seen in the vertebral body. The relationship of the spinal canal to the spinous processes was less abnormal (Figures 5 and 6). The rotational deformity extended beyond the limits of the primary scoliotic curvature in most specimens.

The degree of rotation was always maximum at the apex of the primary curve. It did not bear a proportional relationship to the measurement of lateral deviation by Cobb's method (Table 5).

DISCUSSION

The results of measurement showed that the anterior vertebral body lengths, when measured individually and as total lengths, were almost normal in scoliosis. However, the posterior lengths were found to be considerably less than their corresponding anterior lengths in all of the scoliotic specimens. Further these posterior lengths were signifi-

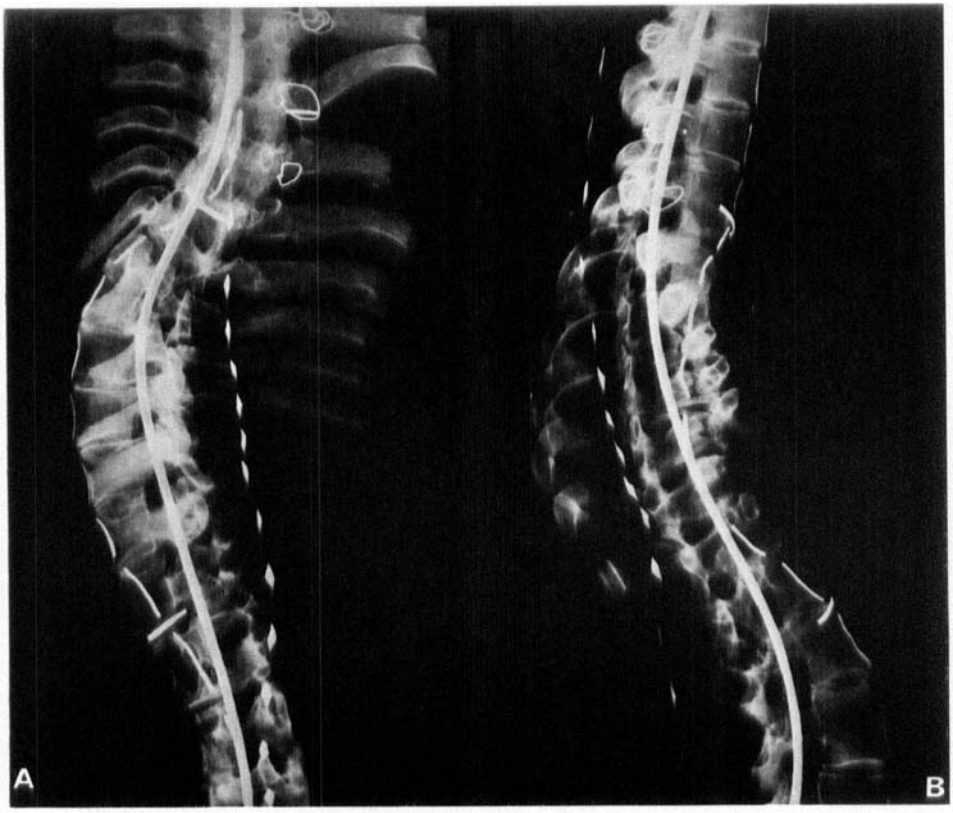
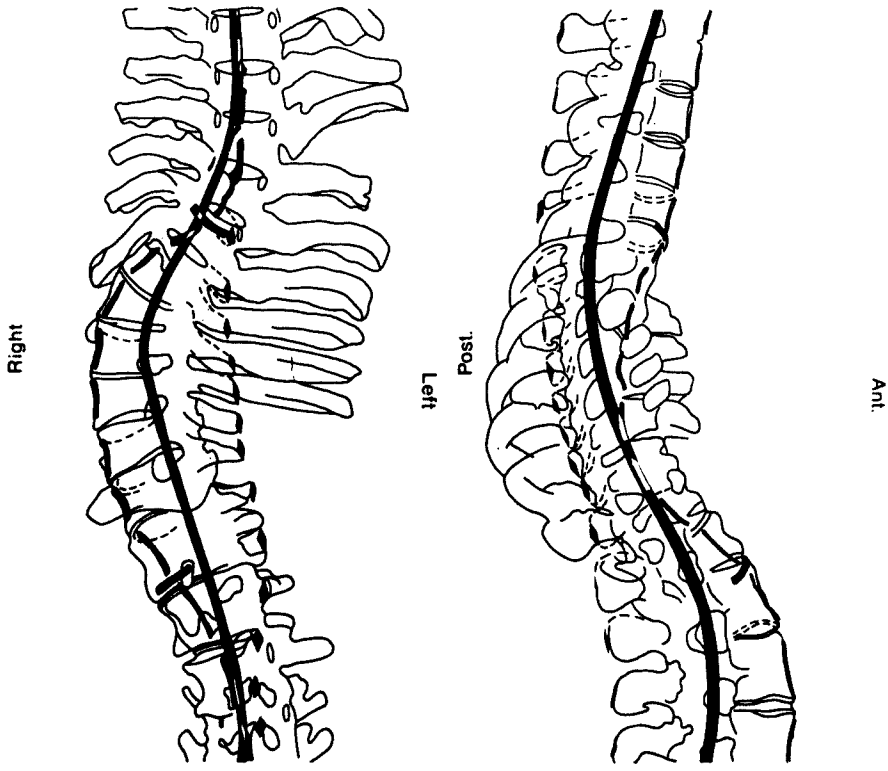


Figure 5. Standard antero-posterior (a) and lateral (b) radiographs of specimen 1 with lead markers and flexible rod in situ. *Note the comparatively normal alignment of the spinous processes (diamonds). The relationship of the spinal canal to the posterior elements was distorted minimally. The maximum distortion was in the anterior vertebral surfaces (vertical lead strips).*

Table 5. Measurement from standard radiographs and tomographs.

Specimen	Standard measurement of curve	Max. measured rotation at apex of primary curve
1	72°	73°
2	36°	63°
3	32°	19°
4	71°	23°
5	118°	58°



Figures 6 a & b. Diagrams to illustrate Figure 5.

cantly reduced from those of the normal spines. This observation was found in all specimens whether the primary curve was kyphotic or lordotic. It appeared, therefore, that the compensatory curves in the kyphotic type may not be only compensatory, but may in addition have some primary growth disturbance leading to a shorter total posterior length. In the normal spines, as expected, the normal thoracic kyphosis was balanced by the lumbar lordosis with all linear measurements being equal. Therefore, longitudinal vertebral body growth would seem to be normal in scoliosis, although the posterior elements of the established curve appeared to have become shorter than normal, regardless of the type of curve that had developed.

From the radiographs it is obvious that the standard scoliosis views do not give a full or accurate interpretation of the complex three-dimensional curvature that characterises the deformity. The standard measurement of curvature by Cobb's method for the quantitative as-

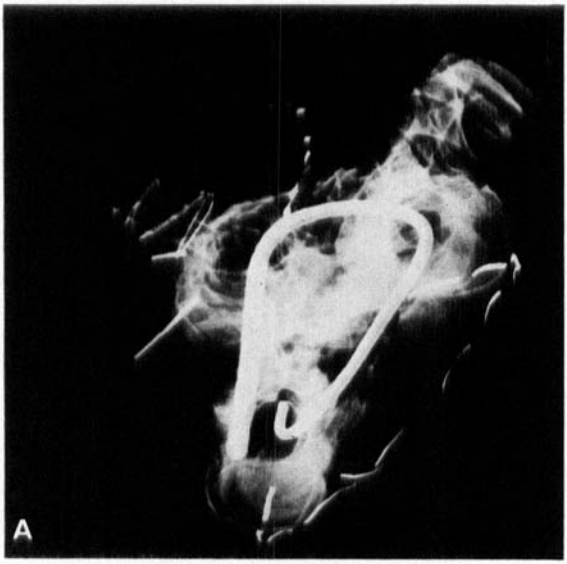


Figure 7 a. Transverse axial radiograph through the total length of marked specimen 1, showing the complexity of the curve and, again, the minimal distortion away from the mid-line of the spinous processes (above centre).

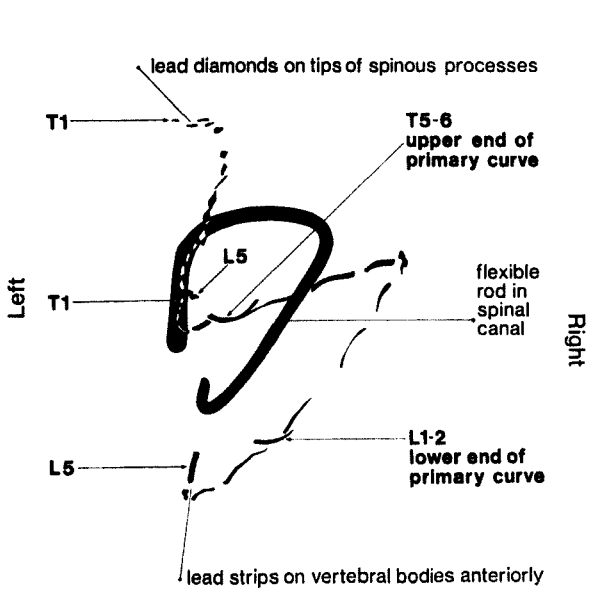


Figure 7 b. Diagram to illustrate the above.

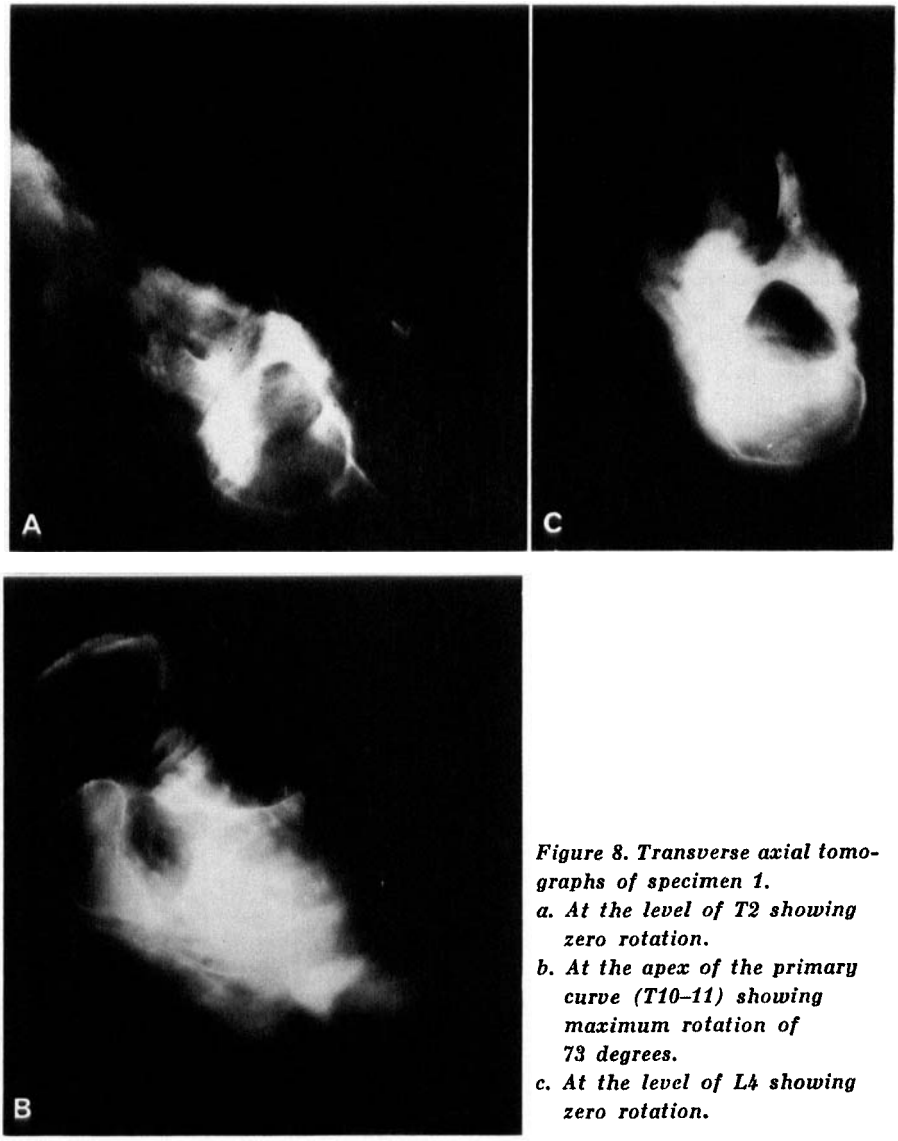


Figure 8. Transverse axial tomographs of specimen 1.
a. At the level of T2 showing zero rotation.
b. At the apex of the primary curve (T10–11) showing maximum rotation of 73 degrees.
c. At the level of L4 showing zero rotation.

sessment of the progress of the deformity and the result of treatment, is liable to error by small alterations in the positioning of the patient. Cobb's method can only measure the lateral deviation of the spine and any assessment of rotation is only an approximation. From this study it is clear that the new transverse axial tomography demonstrated the degree of vertebral rotation present in the curve, and this was measur-

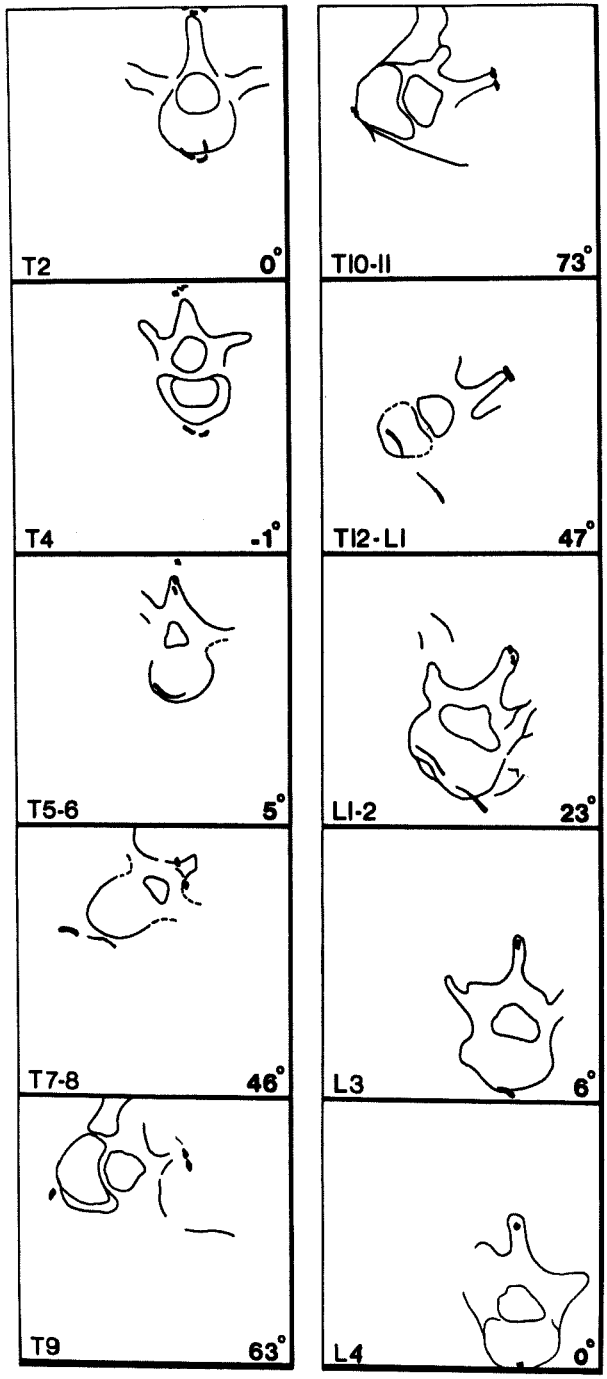


Figure 9. Diagrams traced from the transverse axial tomographs of specimen 1 at 3 cm intervals demonstrating the degree of axial rotation through the specimen.

able. Because this deformity is always present in structural scoliosis and is the most difficult to correct, it is of clinical importance to attempt this type of study in patients. Single transverse axial tomography has been described by Takahashi (1969) for outlining cavity pathology in patients, but not as yet for spinal curvatures.

It has also been observed from this study that the axis around which this rotational deformity occurred was just anterior to the tip of the spinous processes. These latter structures were, in the established curve, least distorted from their original position, confirming Langenskiöld's (1972) observations. However, the axis around which rotation occurs in the thoracic column of normal spines is said to be near the front of the vertebral body (Davis 1959). Thus, the rotational deformity of scoliosis is not an exaggeration of the rotation which is possible in a normal spine. It is suggested that there is some strong inhibiting force to growth posteriorly in the spine, and when combined with normal growth anteriorly the development of scoliosis with rotation and lateral deviation can occur. This force may be regarded as a single longitudinal one acting upon a prismatic column similar to that which D'Arcy Thompson (1942) observed from anthropological studies of animal horn spirals. This he pointed out as behaving quite differently from that of a cylindrical column, in that it underwent a torque movement with deformation of its components (Duthie 1971). The spinal column in the erect human can be regarded as an asymmetrical or prismatic column subjected to the constant longitudinal force of gravity. Therefore, should any abnormal factor of localised growth inhibition or muscle imbalance arise, then the longitudinal force of gravity will act away from the mid-line, and produce a rotation and lateral bending, and thereby continue to increase this deformity. Only if mid-line balance is again achieved will this force cease to increase the deformity.

In conclusion, it is suggested that some inhibition in growth of the posterior elements of the spine may be a sufficient assymetric stimulus to allow the longitudinal force of gravity to produce the characteristic scoliotic curvature, in spite of normal linear growth of the vertebral bodies anteriorly.

SUMMARY

Five articulated scoliotic spines have been studied by serial transverse axial tomography for rotation, and for linear relationships of the vertebral bodies to their posterior elements. It was found that:

1. The normal progression of increase in anterior vertebral body length down the spine has also been found in the scoliotic spine.

2. The anterior body lengths either singly, or as total length, were almost normal in the scolioses, but the posterior lengths were considerably reduced, whether the primary curve was kyphotic or lordotic. In the normal spines the linear measurements showed that the thoracic kyphosis was balanced by the lumbar lordosis.

3. Standard scoliosis views by radiography do not give an accurate interpretation of the complex three-dimensional curvature of scoliosis, and measurement of such radiographs is very liable to error by small alterations in positioning of the spine.

4. The new transverse axial tomographs demonstrated well the vertebral rotation and this was measurable. Possible clinical use of this method was discussed.

5. The axis of rotation occurred near the tips of the spinous processes in scoliotic spines, but in the normal thoracic spine it is said to be near the front of the vertebral body. Therefore, the rotational deformity of scoliosis is not an exaggeration of the rotation found in normal spines.

6. It was suggested that scoliosis results from some strong inhibitory force to growth of the posterior vertebral structures, with normal anterior linear growth.

In the presence of local growth inhibition or muscle imbalance, the constant longitudinal force of gravity acting on the "prismatic" vertebral column can satisfactorily explain the progression of the typical scoliotic deformity.

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Correspondence to:

Professor R. B. Duthie
Nuffield Orthopaedic Centre
Headington
Oxford, England