CURVE PATTERNS IN IDIOPATHIC SCOLIOSIS

A CLINICAL AND RADIOGRAPHIC STUDY

J. L. CRUICKSHANK, M. KOIKE, R. A. DICKSON

From the University of Leeds

We have developed a simple technique for demonstrating the sagittal profile of each rotated level of a scoliotic spine and used it to determine the patterns of lordosis and kyphosis in each of six clinical types of idiopathic scoliosis. The currently accepted classification of scoliosis is inaccurate and a modification is proposed.

The three main types of scoliosis were shown to have sagittal profiles distinctly different from each other and from normal. Single structural curves had short lordotic sections at their apices, limited above and below by kyphosis. Double curves showed longer lordotic sections limited only by one area of kyphosis. Lordosis throughout the thoracic and lumbar spine was associated with triple curve patterns.

The biomechanical effects of the abnormal sagittal profiles provide a simple explanation for the genesis and progression of the different types of scoliosis, and the recognition of the pattern of the sagittal abnormalities permits treatment to be designed on a sound anatomical basis for individual cases.

The three-dimensional nature of the deformity of scoliosis has long been recognised; successive generations of surgeons have studied the anatomy both of scoliosis in general and also of individual patients. Recent reports have re-emphasised the importance of inappropriate lordoses in generating the biomechanical instability causing rotational deformities (Dickson et al. 1984; Deacon and Dickson 1987), but full appreciation of the biomechanics of scoliosis has hitherto been impossible because there was no clear understanding of the abnormalities associated with the development of the different curve patterns.

The underlying sagittal profile of scoliosis is of such importance to biomechanical understanding that its simple radiographic demonstration is essential to the study of an individual deformity. Interpretation of radiographs made lateral to the patient's pelvis or shoulders is very difficult when a rotated deformity is present; none of the affected vertebrae appear in a true view. Usually the lateral curve causes overlapping images of the vertebrae that defy interpretation. Efforts

have been made to use "true" lateral views of the curve apex (Deacon and Dickson 1987) but these require considerable time and skill on the part of the radiographer and trial views are often required before the correct angle is found. The patient may then receive an undesirably high dose of radiation; even then only the apical vertebra is seen in a true lateral view. Separate true lateral views of each vertebra can be made of museum specimens (Cruickshank, Koike and Dickson 1987) but this is not possible in routine clinical practice.

Because scoliosis is a rotated deformity, the conventional anteroposterior view of the scoliotic patient contains considerably more three-dimensional information than is the case in a non-rotated spine. The measurement of rotation from these views has been widely studied and considerably refined (Nash and Moe 1969; Perdriolle 1979; Drerup 1985; Stokes, Bigalow and Moreland 1986). We aim to show that the sagittal profile at each rotated level may also be demonstrated qualitatively on the anteroposterior projection and that a simple overall assessment can be made of the profile at different levels of the structural curve.

J. L. Cruickshank, BSc, FRCS, Lecturer in Orthopaedic Surgery
M. Koike, MD, Research Fellow
R. A. Dickson, MA, ChM, FRCS, Professor
University Department of Orthopaedics, Level 8, Clinical Sciences
Building, St. James University Hospital, Beckett Street, Leeds LS9
7TF, England.

Correspondence should be sent to Mr J. L. Cruickshank.

© 1989 British Editorial Society of Bone and Joint Surgery
0301-620X/89/2060 \$2.00
J Bone Joint Surg [Br] 1989;71-B:259-63.

GEOMETRY

Anteroposterior views of scoliotic patients will show rotation of all the vertebrae in structural curves except those in neutral rotation between the components of multiple curves. Such rotated vertebrae are seen in a projection which is intermediate between truly anteroposterior and lateral. The apparent wedging of

these vertebral bodies reflects a combination of lateral wedging and either lordosis or kyphosis of the vertebra. An exact estimate of the sagittal component of this apparent wedging is not possible from a single view but a qualitative assessment may be made because the tallest part of the vertebra must form the convex aspect of the scoliotic column. If the posterior elements of the vertebra are directed towards the convexity then the sagittal profile of the spine must be kyphotic; if they are directed to the concavity of the curve then the sagittal profile must be lordotic.

MATERIALS

Routine anteroposterior standing radiographs of 90 untreated adolescent idiopathic scoliosis patients with clinically significant curves of differing patterns were selected so as to represent each of the commonly accepted scoliotic curve patterns (Goldstein and Waugh 1973) by equal numbers of cases within the sample. The initial selection was made by simple inspection.

During the course of the study it became apparent that the accepted classification of scoliotic curves was inadequate. Individual consideration of each vertebral level led to the recognition that many curves included minor, but not insignificant, structural components that had not been appreciated on initial inspection. Minor lumbar components were frequent and in particular a large number of curves included a small but consistent upper thoracic component. In view of this finding a modified classification was developed.

Patients were grouped into those with true single curves, those with double curves, and those who proved to have triple curves. These groups were subdivided by site in the conventional manner. The eventual numbers in each group are shown in Table I. There were surprisingly small numbers of true single thoracic curves and double thoracic/lumbar curves. Curves are often classified into these groups without adequate examination of the upper thoracic spine, but more careful examination of these frequently reveals small, but biomechanically significant, upper thoracic structural curves. When these are taken into account, double and multiple curve patterns are found to predominate. Although this finding is not reflected in the currently accepted classification, it has been noted before (Cobb 1948) and merits wider recognition.

METHOD

On standard anteroposterior standing radiographs the rotation at each vertebral level was assessed using the torsionmeter of Perdriolle (1979). Rotation was recorded as positive if the posterior elements were turned to the right of the spine and negative if to the left.

Apparent wedging was assessed by measuring the inclination of the upper vertebral end-plate from the

horizontal at each level using the Oxford Cobbometer (Whittle and Evans 1979). The difference in these angles between adjacent vertebral levels was calculated for each level and was expressed as positive if the wedging produced a curvature of the spine convex to the left and negative if convex to the right.

At each level the product of these two values (rotation $\times$ wedging) was calculated so as to give a number that is positive if that level is lordotic and negative if kyphotic. This number was termed the Sagittal Score. The size of this score does not register the exact degree of lordosis or kyphosis, but, in principle, the greater the score the more lordotic the spine. The score thus provides a qualitative index of the sagittal profile at each level.

In interpreting these scores it is obvious that if rotation is zero, no inference can be made about the sagittal profile whatever the degree of lateral wedging, while if no lateral wedging is detectable in the presence of measurable rotation then the vertebra is neither kyphotic nor lordotic but is square in profile.

Table I. Curve patterns in 90 patients with adolescent idiopathic scoliosis

Single thoracic	7
Single thoracolumbar	18
Single lumbar	12
Double thoracic/thoracic	17
Double thoracic/lumbar or thoracic/thoracolumbar	11
Triple thoracic/thoracic/lumbar or thoracic/thoracolumbar	25

The Sagittal Scores at each level were then compared in the different patterns of curve to demonstrate the abnormalities of sagittal profile associated with each group of deformities.

RESULTS

Single thoracic curves. This group by definition (Goldstein and Waugh 1973) includes all curves with their apex from T2 to T11; however, all seven of the curves we investigated were apical at T7, T8 or T9. They were all lordotic at the apex and for one or two levels above and below this (Fig. 1). The lower limit of the curve in all cases was a short (one or two segment) kyphosis at the thoracolumbar junction. At the upper limit one curve had a square profile segment while one had a single rotated kyphotic level; each of the other curves showed lordosis to the top of the structural curve. Above this level anteroposterior views gave no indication of sagittal

Fig. 1

Fig. 2

Fig. 3

Anteroposterior radiographs. Kyphotic levels are marked with black triangles and lordotic levels with white triangles. Figure 1 - A single thoracic curve with a rotated lordosis from T7 to T12. A rotated kyphosis is present at L1 and L2. Figure 2 - A double thoracic/thoracic curve showing a rotated lordosis from the uppermost vertebra, T3, to T12. A rotated kyphosis is present at L1 and L2. Figure 3 - A triple thoracic/thoracic/lumbar curve showing a rotated lordosis extending from T3 to L3. The vertebrae at the transitions between each element of the curve, T6 and T11, are not seen in a rotated projection and this view therefore gives no indication of the sagittal profile at these two levels.

profile; but lateral radiographs (true lateral projections of non-rotated vertebrae) showed that the normal upper thoracic kyphosis was present.

Single thoracolumbar curves. By definition these curves are apical at T12 or L1. All 18 curves were lordotic at the apical and adjacent segments, but the extent of the lordosis varied from T8 to T11 proximally to L2 or L3 distally. In all cases one or two kyphotic segments were present at the lowermost extent of the curve, that is at L3 or L4. Sixteen of the eighteen curves also had one or more kyphotic segments at the uppermost extent of the structural curve.

Single lumbar curves. These curves are defined as those apical at L2. All 12 showed lordosis at L1 and L2 and a kyphosis at L3 and/or L4. All except two showed a one, two or three segment kyphosis at the upper limit of the curve (T9 to T11).

Double thoracic/thoracic curves. These curves are frequently misclassified as single thoracic curves though they have two apices within the thoracic region (Fig. 2). Typically the apex of the upper curve is at T3 or T4 and is relatively small compared to the lower curve, which may have its apex at any level from T7 to T11. All curves studied showed extensive lordoses through both curves.

In none of our 17 cases could any normal upper thoracic kyphosis be identified; lordosis extended to the uppermost registrable segment which was T2, T3 or T4. At the transitional zone from the upper to the lower component of the curve most of these spines had one non-rotated level for which no estimate of the sagittal profile could be made.

With this exception lordosis was identified at all levels from the top of the upper curve down to T10, T11 or T12. One spine with the apex of the lower curve at T10 showed lordosis extending to L1, while one with a lower apex at T11 showed lordosis to L2. In all except the three least deformed spines one, two or three kyphotic levels could be identified immediately below this area of lordosis.

Double thoracic/thoracolumbar or thoracic/lumbar curves. This group included all curves with a thoracolumbar or lumbar scoliosis combined with a contralateral thoracic scoliosis. In all 11 curves examined the thoracic apex lay in the lower half of the thorax, and all showed extensive lordoses from the upper limit of the deformity at T5 or T6 down to the lumbar spine. Eight of the 11 showed kyphosis at L4, and three were lordotic throughout the lumbar spine. Four spines showed a single

kyphotic level within the deformity. These were at different levels and no pattern to their occurrence was apparent.

Triple thoracic/thoracic/lumbar or thoracic/thoracolumbar curves. This large group of curves, frequently misclassified as double structural curves, have a small upper thoracic curve with larger curves in the lower thoracic and lumbar regions (Fig. 3). All 25 showed lordosis from the highest recordable level (usually T2) down to L3. As with the double curves, a single non-rotated level for which no profile could be determined was common at the transition from one component to a neighbouring one. The majority of these spines showed kyphosis at L4. Single kyphotic levels within the extent of lordosis were noted in a few spines, but no pattern could be identified.

DISCUSSION

The buckling of columns has been studied by engineers interested in designing structures that must not do so (Gordon 1978). The results of these studies are known as Euler's laws and may be used to predict the behaviour of any column of known shape and proportions. The behaviour of curved columns differs from that of straight ones and may be summarised by saying that if force is applied to a rigid curved column so as to tend to increase that curve, then no lateral deviation or twisting of the column will occur even if the force is increased until brittle failure occurs. By contrast, if force is applied so that it tends to straighten the column, then twisting and lateral bending will occur during the phase of plastic deformation. An example of this is the ease with which a metal rod may be bent to contour it to the spine in comparison with the difficulty of straightening it thereafter.

The application of these laws to spinal mechanics is clear and has been stated before (Deacon, Archer and Dickson 1979; Smeathers 1981). If a kyphotic region of the spine is flexed forward then, once the movement allowed by the intervertebral joints has been taken up, the spine retains its contour with little change until fracture occurs. The two normal lordoses in the cervical and lumbar regions of the spine are both mobile and on forward flexion become kyphotic before the limit of travel of the intervertebral joints is reached. They therefore behave similarly. However, if a fixed lordosis is subjected to forward bending it will behave like any other curved column when it is stressed to unbend it: it will twist and bend to the side. A scoliosis must result. If a further bending force is applied, for example by asking a patient with a lordoscoliosis to touch her toes, this rotation will increase; this is the mechanical basis of the clinical test of forward bending.

Any hypothesis for the cause of scoliotic deformity must explain the occurrence of the range of curve patterns which is seen clinically. Clearly, Eulerian

buckling of a fixed lordosis should give rise to a consistent deformity, and the occurrence of different patterns of deformity suggests that they may result from the buckling of different patterns of fixed lordosis. Our study is the first to consider these, and our results show that the sagittal profile of the spines within each curve pattern is consistent within that group and distinct from that of spines in other groups. The expected behaviour, according to Euler's laws, of each of these sagittal profiles can be considered separately.

Single thoracic curves show short apical lordoses limited above by the normal upper thoracic kyphosis and below by a short kyphosis at the thoracolumbar junction. Under forward bending conditions the area of lordosis would be expected to buckle to the side while the zones of kyphosis would exert a strong centring effect. This corresponds to the observed clinical deformity.

Single thoracolumbar curves showed an apical lordosis limited above, and usually below, by areas of kyphosis. The expected biomechanical effect is identical to that described for thoracic curves and corresponds to the clinical picture.

Single lumbar curves also show an apical lordosis limited by regions of kyphosis. At first sight this represents the normal sagittal profile of the lumbar region. A normal lumbar lordosis is however flexible and therefore cannot buckle. In contrast a "fixed" lumbar lordosis is biomechanically identical to the other single curves and will therefore buckle similarly.

Double thoracic curves demonstrated a long lordosis from the top of the thoracic spine to the thoracolumbar junction at which a short kyphosis was present. Since the uppermost thoracic vertebra is effectively fixed in a non-rotated orientation by the functional requirement that the head and neck should "face front", the pattern of buckling generated by forward flexion of a long fixed lordosis is that of a double curve.

Double thoracic/lumbar curves were similarly shown to have a long lordosis extending from the mid-thoracic region through to the lumbar region. Since in neurologically normal individuals the pelvis is functionally fixed in neutral rotation, the mechanics of buckling of such a lordosis are analogous to those in the previous group. A double curve corresponding to the clinically occurring pattern would be expected.

Triple curves showed a lordosis extending throughout the thoracic and lumbar spine. Since both ends of such a long lordosis are fixed in orientation by the requirement that both head and pelvis face forward, buckling under forward flexion would appear to require the production of the triple curve which is seen clinically.

The essence of these findings concerns the response of the rest of the spine to a local lordotic area. A short area of lordosis is balanced by kyphosis above and below to produce a single structural curve. If the local lordotic area extends further upwards or downwards, then there is no area for a balancing kyphosis to produce compensa-

tion. In such circumstances, compensation can only be provided by the development of a contralateral lordoscoliosis with the production of a double structural curve. An upward extending lordotic area thus produces a double thoracic deformity while a downward extending lordotic area produces a double thoracic/thoracolumbar or thoracic/lumbar deformity. If the lordotic area is long in both directions then a triple curve pattern is produced.

In this study we have examined only the anatomy of established deformities. Nevertheless the existence of these abnormal column profiles, with the recognition that the behaviour of such columns under load corresponds to the clinically observed curve patterns, provides a simple and economical explanation both of the genesis and progression of these deformities. If the sagittal profile can be shown to be abnormal, it is unnecessary to postulate any primary neurological abnormality (Herman et al. 1985) or connective tissue disorder (Bushell et al. 1979) for the idiopathic form of scoliosis.

The practical importance of an understanding of the underlying sagittal profile of a scoliotic spine is in its application to the treatment of these deformities. In recent years a number of operations have been developed to correct inappropriate lordosis. The Leeds procedure (Dickson and Archer 1987) of sublaminar wiring to a carefully contoured kyphotic square-ended rod does this, as do the Cotrel-Dubosset technique and several anterior spinal operations. In re-creating kyphosis and reversing inappropriate lordosis it is of crucial importance to recognise both the site and the extent of the abnormal profile. If both these factors are not taken into account and an inappropriate procedure is performed, then the results will clearly be disappointing. And if an abnormal sagittal profile is merely converted to a different abnormal profile, as with Harrington instrumentation, then further buckling and progression of the curve may be anticipated during growth.

Fusion of lumbar curves is frequently followed, after an interval, by disabling low back pain. The realisation that a rigid lumbar lordosis is just as biomechanically unstable as any other fixed lordosis allows this to be understood. Forward bending during the normal activity of such a patient will result in buckling forces in the fused lordotic segments. Not only are the remaining mobile segments subjected to increased flexion and extension forces, but forward bending will also cause considerable torsional stresses with inevitably high risks of intervertebral joint damage. Maintenance of as much of

the normal flexibility of the lumbar spine as is possible should therefore be a prime consideration in any procedure for correcting a spinal deformity.

The rational treatment of scoliosis, as of any deformity, can only be based on an understanding of causative mechanisms. Recognition of the abnormal patterns of sagittal profile and their biomechanical effects can provide this understanding both for untreated patients and for those whose treatment has been successful, or has been unsatisfactory.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

REFERENCES

- Bushell GR, Ghosh P, Taylor TKF, Sutherland JM. The collagen of the intervertebral disc in adolescent idiopathic scoliosis. *J Bone Joint Surg [Br]* 1979;61-B:501-8.
- Cobb JR. Outline for the study of scoliosis. *Am Acad Orthop Surg Instr Course Lect* 1948;5:261-75.
- Cruickshank JL, Koike M, Dickson RA. The sagittal profile in idiopathic multiple curve scoliosis. *J Bone Joint Surg [Br]* 1987;69-B:854-5.
- Deacon P, Archer IA, Dickson RA. The anatomy of spinal deformity: a biomechanical analysis. *Orthopaedics* 1987;897-903.
- Deacon P, Dickson RA. Vertebral shape in the median sagittal plane in idiopathic thoracic scoliosis: a study of true lateral radiographs in 150 patients. *Orthopaedics* 1987;10:893-5.
- Dickson RA, Archer IA. Surgical treatment of late-onset idiopathic thoracic scoliosis: the Leeds procedure. *J Bone Joint Surg [Br]* 1987;69-B:709-14.
- Dickson RA, Lawton JO, Archer IA, Butt WP. The pathogenesis of idiopathic scoliosis: biplanar spinal asymmetry. *J Bone Joint Surg [Br]* 1984;66-B:8-15.
- Drerup B. Improvements in measuring vertebral rotation from the projections of the pedicles. *J Biomech* 1985;18:369-78.
- Goldstein LA, Waugh TR. Classification and terminology of scoliosis. *Clin Orthop* 1973;93:10-22.
- Gordon JE. *Structures: or why things don't fall down*. Harmondsworth, Middlesex: Penguin Books Ltd, 1978.
- Herman R, Mixon J, Fisher A, Maulucci R, Stuyck J. Idiopathic scoliosis and the central nervous system: a motor control problem: the Harrington Lecture, 1983 Scoliosis Society. *Spine* 1985;10:1-14.
- Nash CL Jr, Moe JH. A study of vertebral rotation. *J Bone Joint Surg [Am]* 1969;51-A:223-9.
- Perdriolle R. In collaboration with Boffelli N, and the participation of Ousset M. *La scoliose: son étude tridimensionnelle*. Paris: Maloine SA Éditeur, 1979.
- Smeathers JE. *A mechanical analysis of the mammalian lumbar spine*. Thesis submitted for degree of Doctor of Philosophy, Department of Zoology, University of Reading, 1981.
- Stokes IA, Bigalow LC, Moreland MS. Measurement of axial rotation of vertebrae in scoliosis. *Spine* 1986;11:213-8.
- Whittle MW, Evans M. Instrument for measuring the Cobb angle in scoliosis. *Lancet* 1979;i:414.