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# ANATOMICAL AND BIOMECHANICAL FACTORS IN THE CURVE PATTERN FORMATION OF IDIOPATHIC SCOLIOSIS

TATSUKI KASHIMOTO, TAKAO YAMAMURO & KATSUYUKI HATAKEYAMA

Department of Orthopaedic Surgery, Faculty of Medicine, Kyoto University, Kyoto, Japan

The maximum range of motion between two adjacent vertebrae without soft tissues was measured from C1–C2 down to L5–S and factors such as rotation, lateral bending, extension, and flexion, during surface contact movement of the facet joints, were investigated. Thirty human cadaveric spines were studied. It was found that the individual spines had a characteristic level-dependent difference in the capacity for elementary motions at the facet joints. Those segments with restricted motion capacity were termed "spinal nodes". The human spine usually has three to four spinal nodes between the skull and the sacrum. They are C7–T1, T4–T5, T8–T9, and T11–T12. This intrinsic structural character of the human spine is expressed as "nodal motion structure".

We postulate that this structure plays an important role in the formation of curve patterns in idiopathic scoliosis and other spinal deformities.

*Key words:* curve pattern; idiopathic scoliosis; maximum range of motion; nodal motion structure; spinal nodes

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Descriptions have been made of the topographical classifications of curve patterns seen in cases of idiopathic scoliosis (Ponseti & Friedman 1950, James 1951). However, an analysis of how these curve patterns are formed has apparently not been documented.

The number of curve patterns in idiopathic scoliosis is limited to six to seven. If the human spine is indeed a flexible rosary-like rod with 24 bony components, it should be able to form any type of curve pattern.

The distribution of end vertebrae in 157 spines from patients with idiopathic scoliosis randomly sampled reveals that specific segments of the spines, namely T1, T5, T11, T12, and lower lumbar vertebrae are involved (Figure 1B).

How these phenomena occur, and the local characteristics in the human spine which may be related to these phenomena have long been the subject of investigations (Keller 1924, Gregersen & Lucas 1967).

The objective of our study was to investigate these questions anatomically and biomechanically.

## MATERIALS AND METHODS

Thirty cadavers (24 male and 6 female) were provided by the Department of Anatomy, Faculty of Medicine, Kyoto University, from September 1976 to April 1979. Cadavers with significant degenerative changes at the intervertebral facet joints or of the vertebral bodies were excluded.

The age at the time of death in the youngest was 20 years and in the oldest 85 years, the average being 67.

The individual spines prepared from the 30 cadavers were separated into vertebra leaving the facet joints as

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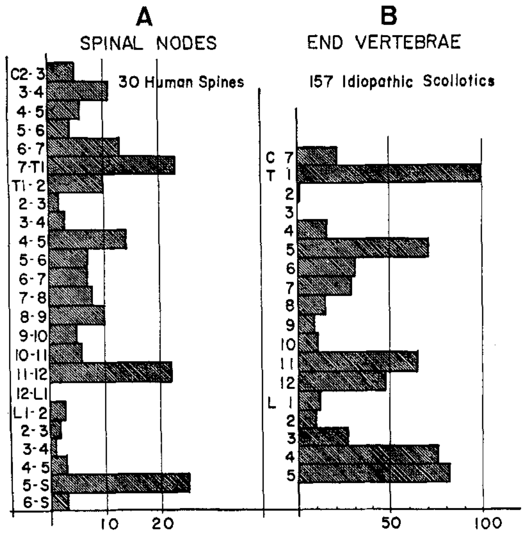

*Figure 1. A: Spinal nodes of rotation in 30 human spines.*
*B: End vertebrae in 157 idiopathic scoliotics.*
*The similarity of the distribution between A and B suggests that the intrinsic structural character plays a role in the formation of curve patterns in cases of idiopathic scoliosis.*

intact as possible. All the soft tissue was removed, including the intervertebral discs.

### *Measurements*

To assess the motion capacity between two adjacent vertebrae, measurements of the maximum range of motion were performed under experimental extremes, though unphysiological.

1. *Rotation* (Figure 2a)
A straight Kirschner wire 2 millimeters in diameter was inserted into each vertebra anteroposteriorly connecting the centers of the vertebral body and the spinal canal. Using a level, the lower vertebra was placed so that the lower surface of the vertebral body was in the horizontal plane. The upper vertebra was rotated horizontally while maintaining contact between the articular surfaces at the bilateral facet joints. The maximum rotation was obtained at the point just before the articular surfaces of the unilateral or bilateral facet joints completely lost contact. The two Kirschner wires were projected to the horizontal plane. A set square was used in the projection. The set square was freely movable in the horizontal plane and had a vertical leg with a height of 2 centimeters on its side. The set square was moved in such a way that the vertical surface accurately followed the Kirschner wire. The rotation angle was thus measured between the two rulers.

2. *Lateral bending* (Figure 2b)
A 2 millimeter diameter Kirschner wire was attached to each vertebra connecting the highest points of the intervertebral foramen under the pedicles. The two adjacent vertebrae were placed on a horizontal plane with the posterior elements upward.

The proximal vertebra was moved during articular surface contact until maximum lateral bending was achieved. The angle of maximum lateral bending was measured at the point just before the facet joint of the convex side completely lost articular contact. The anteroposterior view of these two vertebrae was projected on the horizontal plane. In the projection, the lower surface of the distal vertebral body was placed on a vertical plane, using a set square. To achieve rotational control, the Kirschner wire of the distal vertebra was placed in a horizontal plane, using a level.

The angle of maximum lateral bending was thus measured between two set squares.

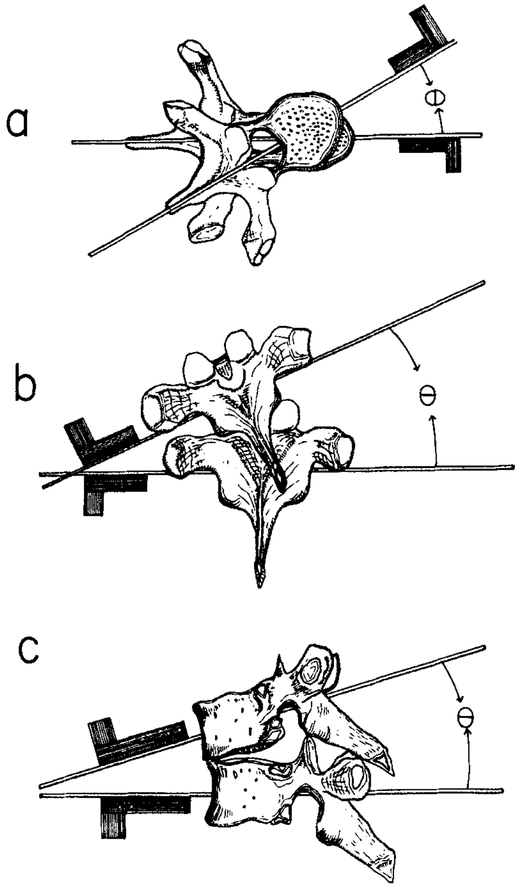

*Figure 2. Measurement of maximum range of motion.*
*a: Rotation*
*b: Lateral bending*
*c: Extension and flexion*

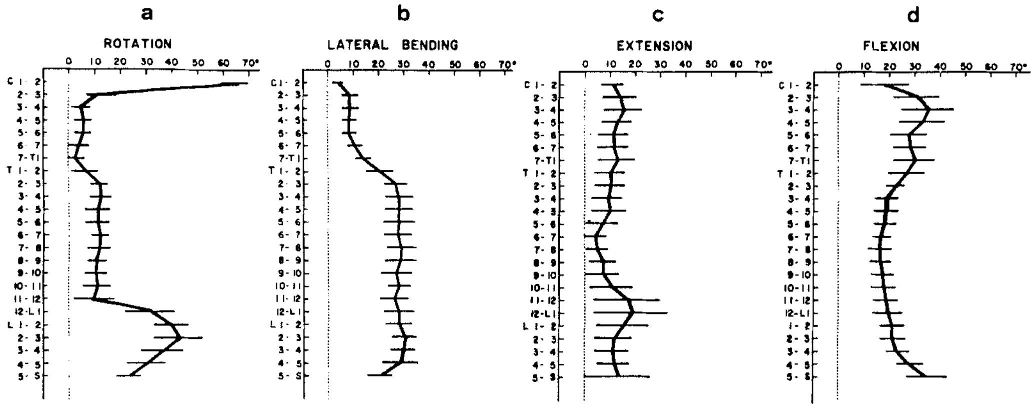

*Figure 3. Curves of maximum range of motion in 30 human spines. Average and standard deviations are shown.*
*a: Maximum Rotation Curve*
*b: Maximum Lateral Bending Curve*
*c: Maximum Extension Curve*
*d: Maximum Flexion Curve*

3. *Extension and flexion* (Figure 2c)

A straight Kirschner wire 2 millimeters in diameter was inserted anteroposteriorly into each vertebra, as in the measurement of rotation.

The neutral position where the facet joints overlap naturally served as 0 degrees.

The maximum extension was obtained at the point where the extension during surface contact movement was stopped by bony contact between the upper and lower spinous processes.

The maximum flexion was obtained when there was no further movement with the vertebral bodies contacting anteriorly and the edges of the superior and inferior articular surfaces contacting posteriorly.

The lateral views of these extensions and flexions were projected on the horizontal plane. The angle of the maximum extension and flexion was thus measured between two set squares.

These values were plotted to form a graphic curve for the individual spine. The curves are termed:

1. Maximum Rotation Curve (M.R.C.),
2. Maximum Lateral Bending Curve (M.L.B.C.),
3. Maximum Extension Curve (M.E.C.), and
4. Maximum Flexion Curve (M.F.C.).

## RESULTS

### 1. *Maximum Rotation Curve (M.R.C.)* (Figure 3a)

The atlas rotates on the axis extremely well. The maximum range of rotation in the thoracic region is generally small and within 20 degrees. The lumbar region possesses an ample capacity for rotation.

A few segments drew attention as they had a limited range of maximum rotation, compared to the adjacent regions. C7–T1, T11–T12 and the lumbosacral junction were particularly conspicuous. We termed these segments "spinal nodes" of rotation. The spinal nodes have an absolutely restricted small value for the maximum range of motion, or a relatively restricted value compared with the adjacent regions, even if the absolute value for the maximum range of motion is not small.

Detailed information of the spinal nodes of rotation of 30 human spines is given in Figure 4. The distribution of the thoracic spinal nodes of rotation is centered over two main segments, T4–T5 and T8–T9. The spinal node located around T4–T5 segment was termed the "upper thoracic spinal node" and the one around T8–T9 as the "middle thoracic spinal node".

In the thoracic region, 14 of the 30 spines had two spinal nodes of rotation between the cervicothoracic spinal node (C7–T1) and the lower thoracic spinal node (T11–T12). Another 14 out of 30 spines had only one spinal node of rotation between the two. The remaining two spines had one spinal node of rotation between the cer-

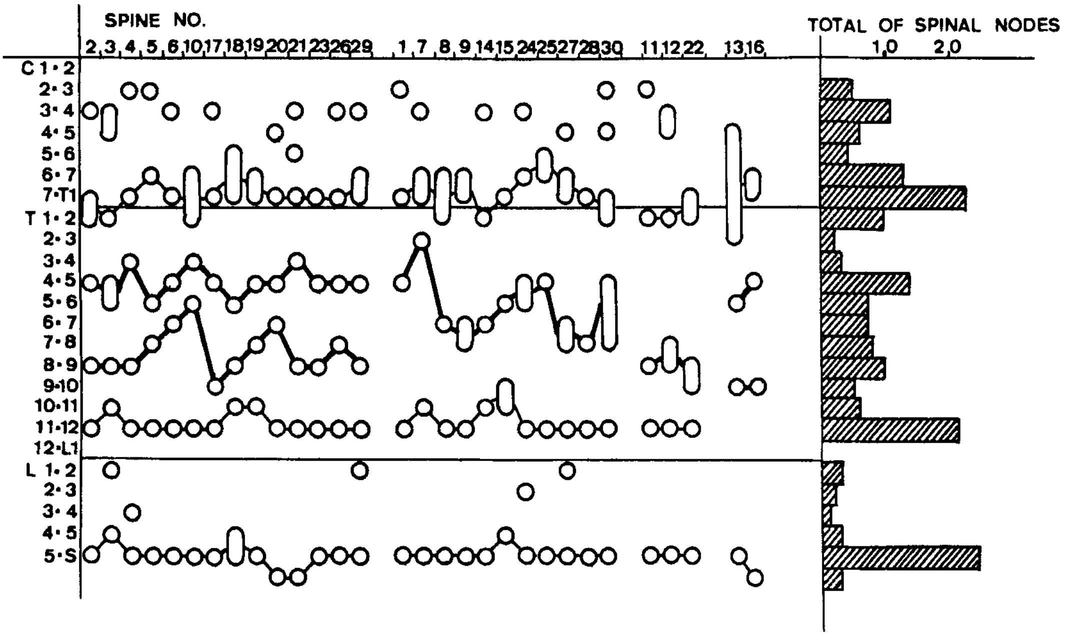

*Figure 4. Level and distribution of spinal nodes of rotation in 30 human spines.*

vicothoracic spinal node and the middle thoracic spinal node (Spine Nos. 13, 16).

Proposed names and segments of spinal nodes of rotation, frequency and statistical data have been tabulated in Table 1.

2. *Maximum Lateral Bending Curve (M.L.B.C.)* (Figure 3b)
In the cervical region, the maximum range of motion is between 5 and 15 degrees. In the thoracic and lumbar regions, 25 to 35 degrees of maximum lateral bending is allowed, depending on the level. In the cervicothoracic junctional region (C5–T2), the maximum range of lateral bending rapidly increases as the level descends.

3. *Maximum Extension Curve (M.E.C.)* (Figure 3c)
The maximum extension is limited in the middle thoracic region (T5–T8) in the majority of the spines (27 spines out of 30). The thoracolumbar region usually has one peak.

4. *Maximum Flexion Curve (M.F.C.)* (Figure 3d)
Cervical and upper thoracic regions have an ample range for maximum flexion. There was a tendency toward restriction of maximum flexion in the thoracic region. In the lumbar region, the range of motion of maximum flexion increases as the level descends.

The distributions of the spinal nodes in M.L.B.C., M.E.C., and M.F.C. are summarized in Figure 5.

## DISCUSSION

Lovett (1905) was one of the early investigators of the human spine. The stiff yet soft tissues of the cadavers in his experiment seem to have influenced the results. Grieve (1979), White (1969) and White & Panjabi (1978) published average ranges of segmental movement of the human spine; however, their results were not based on specific and controlled experiments.

Comparison and correlation of these four types of curves in our study revealed:

1. The human spine is a flexible rod with at least three to four specific segments between the skull and the sacrum where the capacity of motion of the spine is anatomically restricted.

*Table 1. Spinal nodes of rotation*

| Name of the spinal node | Segment involved* | No. of spines out of 30 | Percentage | Significance level** |
|---|---|---|---|---|
| Cervicothoracic spinal node or top node | C6–7, C7–T1, T1–2 | 29/30 | 97% | $P<0.01$ |
| Upper thoracic spinal node or upper node | T3–4, T4–5, T5–6 | 21/30 | 70% | $P<0.005$ |
| Middle thoracic spinal node or middle node | T7–8, T8–9, T9–10 | 21/30 | 70% | $P<0.01$ |
| Lower thoracic spinal node or bottom node | T10–11, T11–12, T12–L1 | 28/30 | 93% | $P<0.001$ |
| Lumbosacral spinal node | L5–S1 | 28/30 | 93% | $P<0.01$ |

* The main segment of each spinal node is underlined.

** Statistical significance was determined by the F test.

The term "nodal motion structure" seems to be suitable to express the intrinsic structural character of the human spine.

2. Each spinal node shows a tendency to occupy a constant and predetermined segment of the individual spine.
3. Details of nodal motion structure are variable and peculiar to the individual spine with respect to number, level, degree and direction of restriction in motion of the individual spinal node.

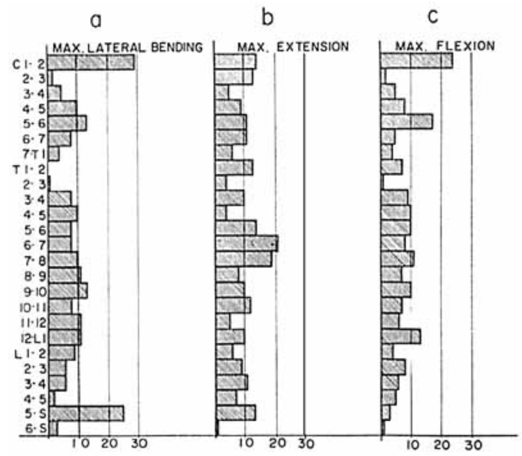

*Figure 5. Distribution of spinal nodes in 30 human spines.*
*a: Maximum Lateral Bending*
*b: Maximum Extension*
*c: Maximum Flexion*

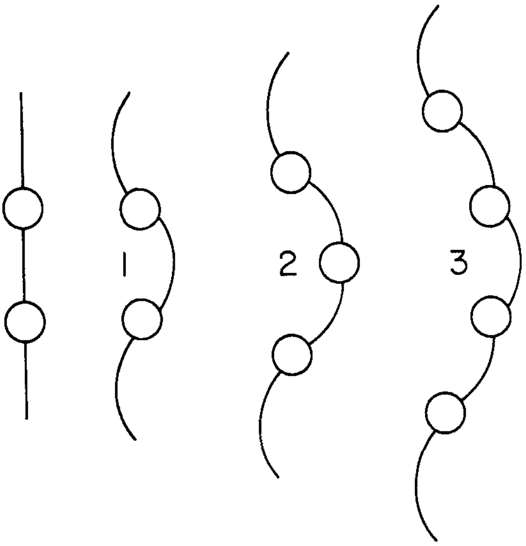

*Figure 6. Basic principles for curve formation in a spine with nodal motion structure. The circles represent the spinal nodes.*

These findings are based on the observations of movements between two adjacent vertebral segments with all soft tissue removed. It is possible that the nodal motion structure can not be seen *in vivo* in the presence of all the connecting soft tissues.

Nevertheless, these findings seem to be helpful in explaining why certain scoliotic curve patterns are formed with the end vertebrae falling almost

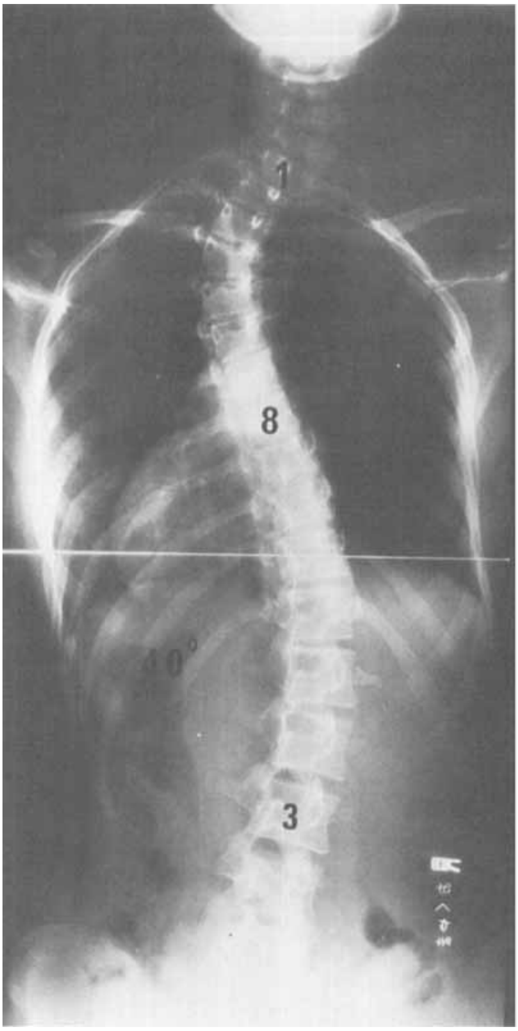

*Figure 7. The major thoracic curve (53 degrees) is formed between the top node (C7–T1) and the middle node (T8–T9). The apex is at the level of the upper node (T4–T5). The thoracolumbar curve is formed between the middle node and L3. The apex is at the level of the bottom node (T12). The compensatory curve is formed proximally in the cervical region and distally in L3–S region.*

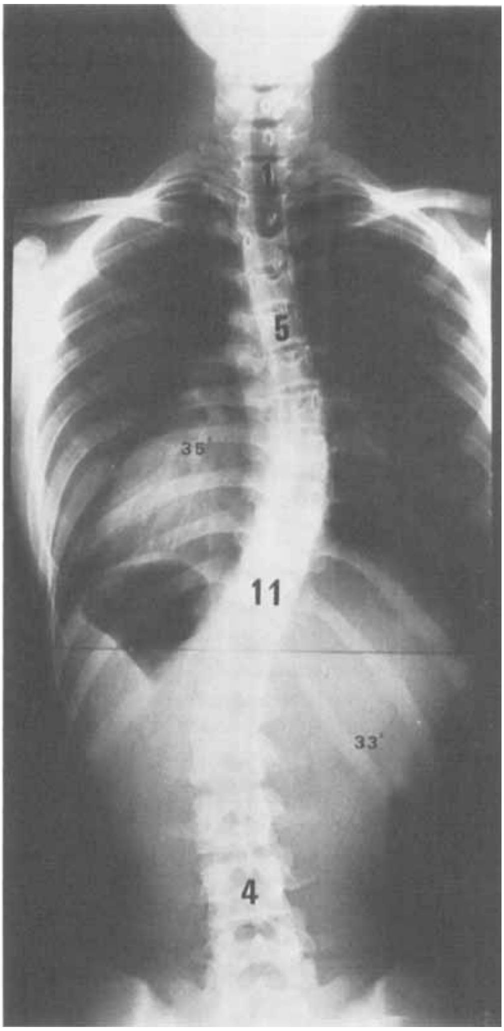

*Figure 8. An example of double major thoracic and lumbar curves. End vertebrae T1, T5 and T11 coincide with top, upper and bottom spinal nodes, respectively. The end vertebra L4 is an "apparent spinal node" (see Discussion).*

constantly upon one of these vertebrae in the spinal node.

Figure 1 illustrates on the left the distribution of the spinal nodes of rotation in 30 human cadaveric spines. The distribution of end vertebrae from 157 idiopathic scoliotic spines is shown on the right. The similarity between the two distributions suggests that the intrinsic structural character of the human spine plays an important role in the formation of curve patterns of idiopathic scoliosis.

The basic principles for curve formation in a spine with nodal motion structure are shown in Figure 6. (1) One curve is formed between two adjacent spinal nodes. (2) The spinal node can be an apex of the curve, when it is sandwiched by

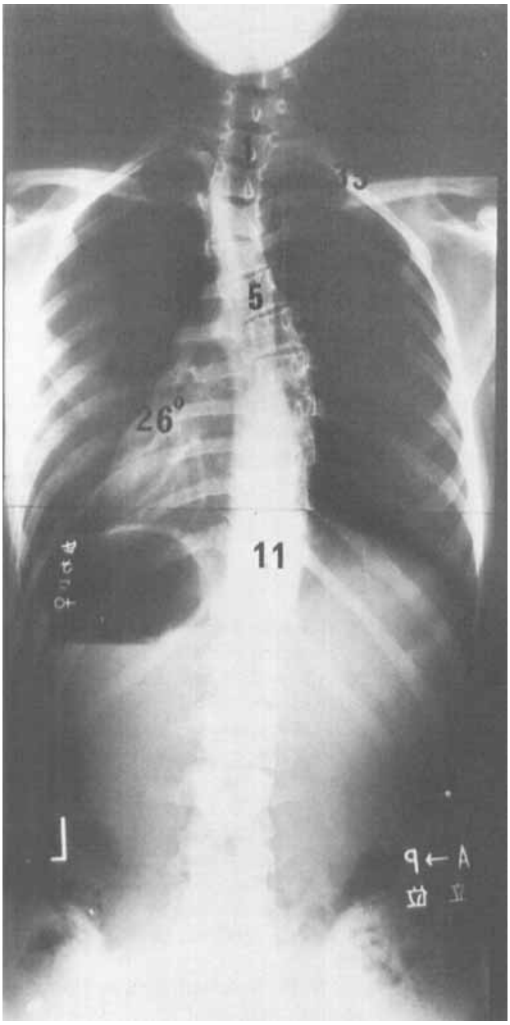

*Figure 9. An example of double major thoracic curves. T1, T5 and T11 coincide with the top, upper and bottom nodes, respectively.*

two segments with a greater maximum range of motion. (3) Theoretically one curve can fall between more than two spinal nodes. (4) The rightening tendency of the spine results in compensatory curves next to major curves.

Many forms of curve patterns are theoretically feasible, on the basis of these principles (Figure 7). The curve patterns clinically observed were re-checked from this point of view, although it was not the objective of this analysis to determine why the individual curve has a predominant side for its convexity (Moe 1978).

(a) *Single major thoracic curves*
This is the curve falling between the upper node T4–T6 and bottom node T11–T12. The apex falls in the T7–T9 region. Compensatory curves are formed proximally between the top node C7–T1 and the upper node T4–T6 and distally between the bottom node and a lower lumbar vertebra.

(b) *Double major thoracic and lumbar curves* (Figure 8)
The thoracic curve falls between the upper and bottom nodes. The lumbar curve is formed between the bottom node and a lower lumbar vertebra. The compensatory curves are seen proximally between the top and upper nodes and distally in the L4–S region, as is discussed later.

(c) *Single major thoracolumbar curves*
This is an example of the bottom node being the apex of the curve. The curve is formed between the middle node T8–T9 and a lower lumbar vertebra, usually L3 or L4. The compensatory curves are formed proximally between the upper node and middle node. The distal compensatory curve is formed in the L3–S region.

(d) *Double major thoracic and thoracolumbar curves*
The proximal curve starts from the upper node T4–T6 and ends in the middle node T8–T9. The apex is located at the T6–T7 level. The distal curve starts from the middle node and ends in a lower lumbar vertebra with its apex at the level of the bottom node.

(e) *Single major high thoracic curves and double major thoracic curves* (Figure 9)
The high thoracic curve falls between the top and the upper nodes. Double thoracic curves add another curve between the upper and bottom nodes.

(f) *Single major lumbar curves*
This curve is formed between the bottom node and the lower lumbar vertebra with the apex at the L1–L2 level. The proximal compensatory

curve is formed between the bottom node and the spinal node located proximal to the bottom node, in most instances the middle node or the upper node. The distal compensatory curve is formed in the L4–S region.

The compensatory lumbosacral curves usually are formed in the L4–S region. L5–S is the spinal node almost constantly, but L5 is not always an end vertebra for lumbar curves. It is extremely rare in idiopathic scoliosis for the sacrum to be an end vertebra for lumbar curves. L5 or L4, occasionally L3, becomes the end vertebra. Rotatability of the vertebra in the coronal plane is a geometrical prerequisite for an end vertebra in a full curve. The top surface of the sacrum in idiopathic scoliotics, however, is usually horizontal in the absence of a leg length discrepancy and cannot rotate in the coronal plane to be an end vertebra. Consequently a more cranially located and freely movable vertebra such as L5 in the spinal node, L4 or occasionally L3, which is not usually in the spinal node, seems to work as an end vertebra for the lumbar curves and compensatory lumbosacral curves. A segment of the spine such as L3 or L4 that works as an end vertebra in spite of the fact that it is not in the spinal node may be termed "an apparent spinal node".

Displacement of the vertebra in scoliosis is in the form of rotation and lateral bending. An analysis of M.R.C. and M.L.B.C. revealed that the distribution of spinal nodes in M.R.C. seems to be related more directly and characteristically to the formation of curve patterns seen in idiopathic scoliosis (Figures 1 and 5a). The spinal nodes in M.L.B.C. which have a rather even distribution in the thoracic region overlap the spinal nodes in M.R.C. and seem to strengthen the node for curve formation.

The influence of the thoracic cage on the curve pattern formation was not considered here. This aspect needs more study in the future.

The nodal motion structure of the human spine, intrinsic and hidden in the normal spine seems to be revealed by the unknown etiology of idiopathic scoliosis and to influence the way the curve patterns are formed.

In extension and flexion, the nodal motion structure does not seem to be directly related to the scoliotic deformity (Figure 5b and c). We assume, however, that this structure plays a role in anteroposterior spinal deformities.

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Correspondence to: Tatsuki Kashimoto, M.D., Department of Orthopaedic Surgery, Faculty of Medicine,
Kyoto University, Sakyo-ku, Kyoto 606, Japan