SCOLIOSIS IN THE GROWING SPINE

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Scoliosis is a term applied to lateral deformation of the axial skeleton. Scoliosis which starts in the growing child is best treated in the growing child. It usually progresses, rarely regresses. It is potentially a catastrophic disease, from both a physical and a psychosomatic standpoint. Although there are some 31 etiologic factors, the most common causes are idiopathic, paralytic (postpoliomyelitic) and congenital (anomalies).

The diagnosis of scoliosis is the simplest of all diseases: LOOK AT THE PATIENT'S SPINE. The prognosis represents probably the most complex and confused compilation of medical literature of any structural disease of man. The treatment is almost as complex as the prognosis, but definitely belongs in the hands of a qualified orthopedic surgeon. The treatment must continue until the growing child reaches maturity.

Regardless of the etiologic factor, the scoliotic spine becomes deformed and progresses structurally by affecting the growth centers of the vertebrae. Unbalanced forces produce asymmetrical growth until the mechanical asymmetrical structure compounds its own deformity by its own growth. There are only three basic elements in scoliosis: (1) growth center of vertebrae; (2) force (gravity and motion); (3) time (time remaining until maturity).

Remove any one of the three elements of scoliosis, and the complexities of prognosis and treatment become simple. This fact can therefore be used as a tool to assist us in evaluating the gravity of the situation.

The growth centers of each vertebra (those primary in scoliosis) are body and right and left facets (load transfer areas), and should have inherent integrity to resist force and time to maturity. Preservation of physiologic integrity of the growth center lies in these load transfer areas. The mechanics are so arranged that reciprocal motion of each segment functions as a force release mechanism. Reciprocal motion demands symmetrical structure. When asymmetrical structure develops, reciprocal motion is sacrificed proportionately. Mechanical forces alone
can become concentrated and overwhelm the physiologic integrity of the growth center.

Any factor that affects the physiologic integrity of the growth centers (body and facets) can be the cause (etiology) or the beginning of a scoliotic deformity. To name a few obvious causes: (a) dysfunction of the collagen fraction of the epiphysis (idiopathic) (lowered physiologic structural integrity); (b) kinetic force imbalance (postpolio-myelitic paresis); and (c) absence of a structural part (congenital hemi-vertebrae).

The time which remains until maturity presents its obvious implication. A child with a mild 20-degree curvature and 3 months of growth remaining in the vertebrae has no problems. But if the curve is incorrectly measured and the remaining growth is misjudged, catastrophe can result (Fig. 70). Therefore useful tools must be developed in order not to make errors in the development of sound judgment.

These tools are simple, but are often misused. They are (1) adequate x-ray study; (2) correct measurement; (3) interpretation of the information obtained.

Our primary concern here is: What is the actual deformity under gravity and motion? Therefore an anteroposterior x-ray picture of the whole spine must be taken in the standing position (Fig. 71). If the whole axial skeleton cannot be taken on one 14 by 17 film, then overlapping films or a 36-inch film is used; but the criteria to be fulfilled must be the whole axial skeleton, including head and pelvis. One view is stressed, and that is anteroposterior only; for scoliosis is our problem, and lateral deformation is to be viewed. When other variations that occasionally accompany scoliosis (kyphosis and gibbus) are seen, then lateral views are indicated. Remember, our primary purpose is information to evaluate the situation.

I recommend the Cobb method of angle of deformity measurement, which requires the identification of transitional vertebrae. The whole spine should be marked, measured and recorded accurately (Fig. 71).

Interpretation of information should be simplified to eliminate the confusion of complexity. I have, therefore, established a factor from the Cobb measurements.4

**Harrington Factor**

The Harrington factor is obtained by simply counting the number of vertebrae in the scoliotic curve, including the transitional vertebrae, and dividing this number into the degree of the curve (Fig. 71). This results in a factor which can be used in a general way to establish a point stability beyond which mechanical stability (reciprocation) is lost. The critical point is a factor of 5. Thus a factor of 5 or more in a growing spine will progress, and the extent to which it will progressively deform
Fig. 70. Roentgenograms of a patient who suffered paralytic poliomyelitis at five years of age. Note that all roentgenograms are reproduced so that they are visualized from the back. A, Patient at 7 years of age; B, at 11 years; C, at 12 years; D, at 13 years; E, at 15 years.
Fig. 71. This anteroposterior roentgenogram of a 16-year-old white girl taken in the standing position on a 36-inch Bucky film at 72 inches represents my criteria for adequate x-ray visualization of an idiopathic sciotic spine. All the markings are unnecessary, but they are possible, useful information. Points to be noted are: (a) the roentgenogram reveals gravity position of the axial skeleton, including head, spine and pelvis orientated as one looks at the back. Right is right and left is left. (b) This double primary curvature is measured by the Cobb method, with the degrees recorded at the apex. The thoracic right deviation measures 30 degrees, and the lumbar (left) deviation 35 degrees. (c) The transitional vertebrae of the major curves are T4, T9 and L3. The transitional vertebrae of the minor curves are C5 and S1. The spine presents, therefore, four curvatures, as marked on the right side of the film: (1) secondary or minor (right) curve between S1 and L3; (2) primary or major (left) curve between L3 and T9; (3) primary or major (right) curve between T9 and T4; (4) secondary or minor (left) curve between T4 and C5. (d) Actually, the axial skeleton, including the occiput and pelvis, presents six deviations as shown marked on the left side of the spine, starting with the pelvis: (1) pelvic gravity postural position in the standing x-ray with a low (5-mm.) left hip; (2) the four previously described primary and secondary curves; (3) a sixth deviation of the occiput on the axial skeleton. (e) When the pelvis is mechanically evaluated by raising a perpendicular from the symphysis, a plumb-line can be visualized which should extend through the length of the film. The arrow at the occiput denotes this gravity plumb-line and reveals 2 facts: (1) the occiput is 1.2 cm. to the left of the plumb-line; (2) the left pelvis is 0.5 cm. wider than the right pelvis. This pelvic (ilium) width represents in a measure the amount of rotation the pelvis is in, whereas the occiput deviation represents the general axial skeletal deviation from the plumb-line (gravity). As seen here in the idiopathic sciotic, the deviation is small and in part represents the
depends, therefore, on the time remaining for growth and the etiology of the scoliosis (physiologic structural integrity of the growth center).

The iliac crest apophysis (Fig. 72) seen to appear in growing children reaching maturity is of assistance in determining roughly the amount of growth to be expected in the succeeding months. It is warned here that active treatment must be continued until this apophysis has closed at both ends. The apophysis usually starts anteriorly and progresses sporadically across the crest of the ilium, and when it closes posteriorly, the vertebral growth centers are considered mature at the same time as iliac apophyseal closure posterior.

The chronologic age of the growing child and the bone age vary as much as two and three years. If one uses chronologic years for interpretation, one could arrive at a definite error in judgment.

All deforming spines (scoliosis) have several curves. The terms “primary,” “secondary,” “major” and “minor” have been used to describe the curves. Our technical knowledge in the mechanical analysis of the multisegmental spine is wanting, and too much emphasis can be placed on major or primary curves and not enough on mechanical significance in this phase of interpreting our situation. Under treatment, the issue is more important than ever, and is another reason for the skill and judgment of a qualified surgeon.

Forces created by gravity and motion are used by man to maintain a physiologic integrity of his structural tissue. We all know that excessive forces in a short time interval result in fracture of bone or ligaments, or both. We further realize that no activity (force of gravity and motion) can create an atrophic state in man’s structural tissue. Between these extremes we regard normal activity as mandatory to maintain physiologic structural integrity.

The axial skeleton of any growing child is under pressure all waking, active hours unless the child is lying down (flat) or buoyant in water. Then muscle tone and activity are the only forces acting on the spine. All other structural systems have pressure release mechanisms in the biped (Homo sapiens) by functioning as brachiation (arms) or walking (legs). Reciprocal of the spine in motion is the only pressure release mechanism the axial skeleton has. Changes of pressures of compression or tension on growing structural tissues are physiological; but, when they become irreversible, i.e. all compression or all tension, then pathologic structural changes are inevitable.

In the growing child’s structural physiology these positive changes cause actual deformities of that structure. This rule applies to all structural physiology.

compensation of the spine in general. (f) The Harrington factor is noted to the left of the left numbers 2 (F 5.0), 3 (F 4.0) and 4 (F 5.0). The factor is derived by counting the number of vertebrae in the curve, including the transitional vertebrae, and dividing this number into the degrees of the curve.
Fig. 72. The iliac crest apophyseal growth center is shown in its various stages of ossification as the patient reaches maturity. A, The arrow points to a beginning ossification of the iliac apophysis in a 12+ 6-year-old. B, The arrow points to the ossifying iliac apophysis which progresses posteriorly in a 13+ 2-year-old scoliotic. C, The arrow points to several proximal rib epiphyses which are still open in this patient (same patient as in B). The importance of this observation will be shown in D, E, F and G. D, The arrow points to an ossifying iliac crest apophysis
Fig. 73. Four idiopathic scoliotic patients between the ages of 12 and 18 years are presented. These patients represent the four basic deformities seen in idiopathic scoliosis: A, primary lumbar; B, primary thoracic; C, double primary, and D, thoracolumbar. Note the general trunk alignment and the elbow level compared to the waist level.

**TYPES OF SCOLIOSIS**

The general etiologic distribution of 100 scoliotics is as follows: 75 per cent idiopathic, 12.5 per cent postpoliomyelitic, 12.5 per cent others. In the category others we have the distribution of 50 per cent congenital anomalies, 25 per cent neuropathic, 20 per cent myopathic, 5 per cent epiphysial dysfunctions.

The idiopathic scoliotics are by far the most numerous, and over 90 per cent are girls. They develop almost characteristic types of curves. The four basic types are (1) primary lumbar, (2) primary thoracic, (3) double primary, (4) thoracolumbar (Figs. 73, 74). Rarely, if ever, do they develop pelvic obliquity. The extent of the major or primary curve is usually spoken of as being mild (15 to 35 degrees) (Fig. 75, A); moderate (35 to 75 degrees) (Fig. 75, B); severe (75 to 150 degrees) (Fig. 75, C). Most curves find the thoracic segments deviated to the right.

The paralytic (postpoliomyelitic) scoliotics are fairly equally divided in sex. Many classifications of types have been described, and I shall not confuse the issue except to say that treatment must be designed to
Fig. 74. The patients shown in Figure 73 present moderate structural lateral curvatures as visualized by roentgenograms in the standing position. All are analyzed by the Cobb measurement and recorded in the following table from an anteroposterior roentgenogram in the standing position.

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<tr>
<th>PT.</th>
<th>TYPE OF CURVE</th>
<th>SEX</th>
<th>AGE</th>
<th>DEGREE</th>
<th>NO. VERT.</th>
<th>FACTOR</th>
<th>TRANS. VERT.</th>
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<td>R</td>
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<tr>
<td>A</td>
<td>Lumbar</td>
<td>F</td>
<td>16+</td>
<td>28°</td>
<td>42°</td>
<td>3</td>
<td>7</td>
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<tr>
<td>B</td>
<td>Thoracic</td>
<td>F</td>
<td>15+</td>
<td>67°</td>
<td>37°</td>
<td>8</td>
<td>6</td>
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<tr>
<td>C</td>
<td>Double prim.</td>
<td>F</td>
<td>12+</td>
<td>46°</td>
<td>48°</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>D</td>
<td>Thoracolumbar</td>
<td>F</td>
<td>18+</td>
<td>40°</td>
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Note the alignment of the occiput over the pelvis and the general alignment of the chest to the pelvis.
Fig. 75. Double primary scoliotic spine. A. Considered mild in extent (between 15 and 35 degrees); B. Considered moderate in extent (35 to 75 degrees); C. Considered severe in extent (75 to 150 degrees).
reach maturity with a stable and straight axial skeleton assisting available function and not aborting it. Most postpoliomyelitic scoliotics (kinetic force etiology) develop pelvic plane deformities described as tilt, obliquity, rotation, and so on (Fig. 76). Axial skeletal function and alignment include the pelvis in my estimation, and functional or structural deformity of the pelvis is important, but too complex for consideration here.

Fig. 76. Roentgenogram of a nine-year-old postpoliomyelitic patient with extensive pa-
resis. The x-ray demonstrates pelvic malalign-
ment with considerable obliquity, some tilt and some rotation.

The other types of scoliosis, consisting mainly of congenital anomalies, have their own peculiar patterns of deformity depending on the extent, site or nature of the etiologic factor in the time of growth in the developing child.

TREATMENT

Treatment depends upon the situation. Success of treatment depends upon (1) diagnosis, (2) evaluation of situation, (3) armamentarium of the responsible orthopedic surgeon, and (4) the cooperation of the patient or parent, or both.

The pediatrician’s responsibility should include only detection; then
he should become a close consultative ally of the adequately trained orthopedic surgeon.

In general, diagnosis is not difficult, at least not critical, as to outcome of the total problem. Evaluation of the situation is critical in most instances. Often adequate armamentarium is lacking, and of course cooperation of the patient or parent is the deciding factor of any treatment. Because of the time interval (long) and surgical procedures, as well as restraining devices such as braces and casts, this cooperation is a necessity.

Of all armamentarium available today, only a few have proved their worth. They are the Milwaukee brace, Risser localizer cast, turnbuckle cast, spine fusion.

Because I am the author of a surgical procedure of spine instrumentation, I must include my own armamentarium, which consists of (1) spine instrumentation to correct and stabilize the spine from T 1 to and including the sacrum for a reasonable length of time; (2) spine fusion—always accompanies instrumentation; (3) cast, always follows instrumentation; (4) Milwaukee brace—used in special cases; (5) research: (a) mechanics of the spine; (b) biophysical chemistry of the growth centers of the spine; (c) cardiopulmonary function in the scoliotic patient.

The four basic types of idiopathic scoliosis shown in Figures 73 and 74 are shown managed by spine instrumentation, fusion, and cast for at least three months (Figs. 77, 78). Spine instrumentation and fusion has now been performed on over 400 patients. Remember that all scoliotic spines at one time were manageable. The results are often related to the proper thing being done at the proper time.

**Spine Instrumentation**

This mechanical instrument is a metallic system designed to attach to the posterior elements of the spine from T 1 to the pelvis. The system has two basic forces that may apply to the spine. They are distraction and compression. These forces have been found to create the following desirable conditions in the segmental column for a reasonable length of time: correction of malalignment, fixation and adjustability (Figs. 77, 78). The distraction force is the principal correcting force in the malformed spine and is adjusted by the ratchet principle. The distraction rod is a prestressed instrument designed for a yield point over 400 pounds on axial loading and over 200 pounds on eccentric loading. The compression rod, which is adjusted by the thread-nut principle, is designated in two sizes, the smaller being flexible to allow ease of introduction around a curve. Each rod has its own particular purchasing hook. The forces of compression and distraction rods are applied to the spine through bone purchasing hooks. The bone purchasing hooks
Fig. 77. The four basic idiopathic scoliotic curves shown in Figures 73 and 74 are analyzed after spine instrumentation and fusion. These roentgenograms are taken in the reclining position and immediately after operation. All films are analyzed by the Cobb measurement and recorded in the following table.

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<th>PT.</th>
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<td>0°</td>
<td>14°</td>
<td>3</td>
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<tr>
<td>B</td>
<td>Thoracic</td>
<td>F</td>
<td>15+</td>
<td>18°</td>
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<td>6°</td>
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<td>D</td>
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<td>F</td>
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<td>0°</td>
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Note the alignment of the occiput over the pelvis and the alignment of the chest to the pelvis as well as the restoration of chest symmetry.
Fig. 78. The same 4 patients are now presented by photographs in the sitting position within 14 days after surgery when the wound is healed and just before the moulded body plaster of Paris cast is applied. Note the general alignment of the occiput, chest and pelvis, and particularly the position of the elbows with relation to the waist. The increase in height of these patients varied between 1¾ and 2¼ inches.
attach to the posterior elements of the spine at predetermined vertebral sites such as transverse processes, facets and lamina. The various bone attachments have a wide range of pressure-resistant tension.

**Harrington Factor**

The scoliotic spine must be evaluated by the Cobb method from a standing unmolested anteroposterior x-ray film as in Figure 79. A factor of 8.3 is derived by dividing 9 into 75 (the number of vertebrae in the curve into the degree of curvature). Likewise, a factor of 10.5 is assessed to the lumbar curvature. In the postoperative x-ray film the curvature has been corrected to 15 degrees in the thoracic segment with a factor of 1.2, and 18 degrees in the lumbar segment with a factor of 3.6.
FACTOR AND ITS USE. The factor of 5 has been established as a reason-
able figure by trial and analysis. The following rules may apply to the
use of the factor in the scoliotic spine.

Rule I. When the factor of 5 is reached or exceeded and growth re-
 mains in the deforming spine as determined by the iliac apophysis,\(^6\) then progression of the curve is inevitable without active treatment, and
instrumentation may be considered seriously.

Rule II. When the factor of 5 is reached or exceeded in the adult
spine, minimal progression by soft-tissue deformation will occur with
time (about 1 degree per year\(^5\)).

Corollary I. When the factor is below 5 in the growing spine, active
treatment can hold the deformation from progression.

Corollary II. When the factor is below 3, not only can progression
under active treatment be stopped, but also geometrical asymmetry can
be reversed. Spine stability can be restored and will remain stable after
maturity without surgical intervention.

Active treatment in my opinion is any method which controls the
spine's integrity during activity (forces of motion and gravity). There
are only two reasonably successful nonsurgical systems that will correct
the spine and allow moderate activity: the Risser localizer cast and the
Milwaukee brace.

The success of active, progressive nonsurgical therapy in the idiopathic
scoliotic spine depends upon the extent (severity of precollagen dys-
function) and time of duration of the endochondral bone-forming zone
dysfunction. This dysfunction is in the precollagen matrix of the
columnar zone of the ossification zone. The biophysical chemistry of
the mucopolysaccharides, chondroitin sulfate, and collagen formation
will one day reveal a successful therapeutic approach. Then active
chemotherapy will abort this pathologic state of the growing spine.
Prophylactic treatment will require an identification of the dysfunction
as proposed by Ponsetti, but neither a laboratory test nor a treatment
exists today.

Rules of Instrumentation Use

A factor of 5 or more must be present before this system is indicated.
There must be one of the following three signs or symptoms present to
warrant the system's use: (1) progression of the curve (children), (2)
progression of pain-fatigue (adult), (3) physiologic compromise (pul-
monary and cardiac).

The following rules apply to an unmolested standing anteroposterior
x-ray film of the axial skeleton with lateral deformation (Fig. 71).

1. Establish the major curve with its transitional vertebrae identified
and the number of vertebrae in the curve, including the transitional vertebrae by the Cobb method.

2. Establish all other compensation curves by the same method.

3. Primary forces to be applied by this system are (a) distraction (antigravital). The distraction force is applied at or beyond the transitional vertebrae above one vertebra, below one or two vertebrae beyond the transitional vertebrae in the major curve. (b) Compression (segmental correction). The compression force is applied inside the transitional vertebrae by multiple purchase.

4. Secondary forces are considered supplementary forces and are applied by the following rules in relation to the triangle formed by the two lumbosacral facets composing the base of the triangle and the centroid of the vertebra being purchased on by the main distraction force: (a) sacral triangle (isosceles). If the centroid of the vertebra being purchased on by the main distraction force forms an isosceles triangle with the lumbosacral articulation (apex is over the base), the system will not need supplementation. (b) Sacral triangle (obtuse). If the centroid of the vertebra being purchased on by the main distraction force forms an obtuse triangle with the lumbosacral articulation (apex is not over the base), the system will need supplementation.

Fig. 80. This roentgenogram of the patient seen in Figure 76 demonstrates the use of the sacral bar in restoring the pelvic alignment deviations.
Fig. 82. A four-year-old severe idiopathic scoliotic patient is presented to demonstrate the extremes of ages in which the instrumentation can be used, and the results obtained. This patient is now being managed in a Milwaukee brace until she reaches nearer to maturity, when spine fusion will be done to ensure more permanent results. The instruments will be adjusted at one-, two- or three-year intervals to keep up with growth.
Supplementary instruments are overlapping distraction force, universal hook and the sacral bar (Fig. 80).

**SUMMARY AND CONCLUSIONS**

The important factors to consider when using spine instrumentation to correct or stabilize the axial skeleton are as follows:

1. This prestressed metallic system for axial skeleton application corrects and stabilizes only for a reasonable and usable length of time.

2. Metal does not cure disease. The etiologic factor of the pathologic state requiring the use of this system must be a primary consideration.

3. A knowledge of the working forces of the system is mandatory.

4. A knowledge of the malformed, unstable axial skeleton and its biomechanics is essential.

5. A sincere respect for the extent of the operation required to apply instrumentation demands an organized procedure by a trained surgical team.

6. The importance of postoperative management must be fully realized, and a program of management provided which takes into account the etiology of the condition and the period of active growth.

Fig. 83. Roentgenograms of patient shown in Figure 82.
Fig. 84. This 35+ year-old severe sciotic patient represents the age range in the use of this metal system.

Fig. 85. Roentgenograms of patient shown in Figure 84.
Fig. 86. This 12-year-old patient represents the deformity seen in congenital (hemivertebra) scoliosis.

Fig. 87. Roentgenograms of patient shown in Figure 86.
remaining. A well molded plaster of Paris body cast (Fig. 81) should be applied after operation for 12 weeks or longer in nearly all cases.

Complications occur, but are correctable and have been minimized with time through design changes, alterations of postoperative immobilization, and by refinements in surgical technique. The rules of application are simple and all-inclusive. They apply to the spine from the first thoracic segment to and including the pelvis. The variables of age (4 to 40 years) (Figs. 82 through 85), etiology (paresis, idiopathic, congenital) (Figs. 86, 87), and time (growth) only add to the complexity of the problem. The extent to which a patient can be benefited lies within a total understanding of the problem (disease process) by the surgeon and the patient. Good results are the reflection of effort and understanding applied through a prolonged period of time.

Scoliosis is a serious disease of growing children. The diagnosis is simple and should not be confused with prognosis and treatment. Active treatment is essential by a qualified orthopedic surgeon for the correlation of prognostic complexity; and the extent of necessary treatment measures the success of the final results. All scoliotic spines must pass through manageable stages.

REFERENCES


Baylor University College of Medicine
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