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Treatment of Scoliosis

Correction and Internal Fixation by Spine Instrumentation *†

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The development of the treatment of scoliosis to be described began in 1947 with a study of the anatomy of the spine and the problem of scoliosis as seen in approximately 3,000 patients with poliomyelitis. It was thought that a metal device for the correction of the scoliotic curve and for the maintenance of the correction could be implanted, and in the period between 1949 and 1954 such a device was used in nineteen patients (Table I). Thirty-five modifications in the

TABLE I

GROUP I

NAME	SEX	AGE	DIAGNOSIS	FUSION		RESULTS			NUMBER OF OPERATIONS	SEVERITY OF CURVATURE			CAST		COMPLICATIONS									ILEUS			DEATH	REMARKS
				YES	NO	BETTER	SAME	WORSE		MILD	MODERATE	SEVERE	YES	NO	PSEUDO-ARTHROSIS	SURGICAL SHOCK	BONE EROSION	INSTRUMENT FRACTURE	INSTRUMENT DISLOCATION	RADICULITIS	INFECTIONS	METAL REACTIONS	PROGRESSION 2ND CURVE	MILD	MEDIUM	SEVERE		
BB	F	19	I	X			X		3			X			X			X	X									
VB	F	14	PP	X		X			2			X					X	X										
MC	F	33	PP	X		X			2			X						X										
JC	M	12	PP		X		X		4		X						X	X										
JE	F	11	I		X			X	2	X																		
JF	M	16	I	X		X			1		X				X													
DH	F	20	PP	X			X		11			X			X		X	X										
RH	M	9	PP					X	1		X						X					X						
KL	F	16	PP	X		X			3			X																
IM	F	25	PP	X		X			2		X				X		X	X										
GP	F	14	PP	X		X			3		X						X	X										
CO	F	14	PP	X				X				X					X	X										
JR	F	12			X		X		3		X						X	X										
LS	F	16	PP	X		X			2		X																	
HS	M	15	PP	X		X			1	X							X	X										
SW	F	12	PP		X		X		3		X						X	X										
JW	M	14	PP			X			4			X						X										
AW	F	18	I	X		X			2	X							X											
LW	F	13	PP		X	X			1		X																	
19			19	13	6	11	5	3	53	3	9	7	0	0	4	0	10	11	0	0	0	1	0	0	0	0	0	0	0

DIAGNOSIS KEY

PP—POST POLIO
I—IDIOPATHIC

Table I represents the nineteen cases in Group I of the study in which the major instrument development took place. The complications of bone erosion, instrument fracture, and pseudarthrosis dominated this series. Note that no casts were used and that fusion was used in nearly all cases eventually to acquire reasonable results.

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device were made during this five-year period. Many problems were encountered; and the period between 1955 and 1960 saw the development of other modifications, principally of the instrumentation, but also of the surgical approach and clinical application of the original idea (Table II). Forty-six patients were operated on in this phase of the study, and twelve modifications of the device were made in this period. During 1960, sixty-eight patients were treated by the method as perfected up to that point (Table III). A description of the method presently in use is the main subject of this article.

TABLE II

GROUP II

Name	Sex	Age	Diagnosis	Fusion		Results			Number of Operations	Severity of Curvature			Cast		Complications													
				Yes	No	Better	Same	Worse		Mild	Moderate	Severe	Yes	No	Pseudo-arthrosis	Surgical Shock	Bone Erosion	Instrument Fracture	Instrument Dislocation	Radiculitis	Infections	Metal Reactions	Progression 2nd Curve	Ileus: Mild	Ileus: Medium	Ileus: Severe	Death	Remarks
C B	F	17	I	X		X			2			X												X				
J B	M	15	PP	X		X			3		X						X							X				
J B	F	23	PP	X		X			2			X												X				
P B	M	14	PP	X		X			4			X					X	X						X				
T B	M	15	PP	X		X			3		X						X							X				
D B	F	18	PP										NO OPERATION YET															
J B	M	11	I	X		X			3			X												X				
S B	F	11	PP		X			X	3		X						X	X						X				
T C	M	10	.PP	X				X	4		X						X	X							X			
C	M	—	PP										NO OPERATION YET					--						X				
C C	F	20	PP	X		X			1	X														X				
T C	F	11	PP	X		X			2		X													X				
S C	F	—	I		X			X	1	X							X							X				
R C	F	14	PP	X		X			1		X						X							X				
E.C	F	13	PP	X				X	3			X					X	X							X			
B.C	M	—	PP										NO OPERATION YET															
J.C.	M	13	PP		X			X	3			X					X	X						X				
S.C.	F	8	PP		X		X		2		X						X							X				
B.E.	M	12	PP	X		X			2			X					X	X						X				
J.E.	M	12	PP		X		X		2			X					X	X						X				
C.F.	M	11	PP		X		X		4	X							X							X				
D.H.	F	20	PP	X			X		11			X			X		X	X						X				
J.H.	F	16	I	X		X			2			X											X	X				
S.H.	M	12	PP		X		X		3		X											X–18 MONTHS			X			
L.J	F	13	PP		X		X		2		X													X				
B.J	F	12	I	X				X	3		X				X		X						X	X				
B.J	F	13	PP	X			X		1	X														X				
K.L	F	16	PP	X		X			3			X												X				
F.L	M	18	PP	X		X			1			X												X				
G.M	M	15	PP	X			X		1		X													X				
B.Mc	M	11	PP	X			X		3			X					X	X						X				
B.M	F	15	PP	X		X			1			X												X				
K.M	F	10	PP		X	X			3		X													X				
F.M	M	11	PP	X		X			2		X													X				
D.N	M	8	PP	X		X			2									X						X				
P.P	F	14	PP	X		X			4		X				X			X						X				
L.P	M	15	PP		X			X	3			X					X	X						X				
R.P	M	18	PP	X		X			1			X												X				
F.R	F	13	PP	X		X			2		X						X							X				
J.R	M	10	PP		X			X	1			X					X	X						X				
R.R.	F	7	PP		X	X			1			X					X							X				
J.S	F	10	PP	X		X			3			X					X							X				
L.S	F	16	PP	X		X			2		X	.												X				
H.S.	M	15	PP	X		X			1	X														X				
P.Vs.	F	—	PP										NO OPERATION YET												X			
J.W	M	14	PP	X		X			4			X					X	X						X				
			46	30	12	25	9	8	105	5	16.	20	0	0	3	0	22	14	0	0	0	1	2	37	4	0	0	0

DIAGNOSIS KEY

I—IDIOPATHIC
PP—PARAPLEGIC

This table represents Group II, or the research group which was supported by a National Foundation grant, and consists of forty-six patients, forty-two of whom were operated on from 1955 to 1960. Note that fusion was used extensively to accomplish better results and that no casts were used. The instrument design and force application became better and greater, and bone erosion increased as well. Instrument fracture became less frequent than in Group I. The number of operations to reach a reasonable result was less in this group than in Group I.

The device includes several component parts, all made of S Mo 18–8 stainless steel. The device is designed to exert (1) a primary corrective force on the curve, using distraction on the concave side and compression on the convex side of the scoliotic spine (Fig. 1) and (2) a supplementary secondary stabilizing force on the lumbosacral spine when indicated (Fig. 4). The distraction rod is a prestressed rod (one-quarter of an inch in diameter). Rods ranging from three and three-quarters to fifteen and three-quarters inches in length, in one-inch increments, are

TABLE III

GROUP III

NAME	SEX	AGE	DIAGNOSIS	FUSION		RESULTS			NUMBER OF OPERATIONS	SEVERITY OF CURVATURE			CAST		COMPLICATIONS											ILEUS			DEATH	REMARKS
				YES	NO	BETTER	SAME	WORSE		MILD	MODERATE	SEVERE	YES	NO	PSEUDO-ARTHROSIS	SURGICAL SHOCK	BONE EROSION	INSTRUMENT FRACTURE	INSTRUMENT DISLOCATION	RADICULITIS	INFECTIONS	METAL REACTIONS	PROGRESSION 2ND CURVE	MILD	MEDIUM	SEVERE		
R.B.	M	16	I		X		X		2			X		X	X				X					X				
M.B.	F	15	F	X		X			1		X			X														
M.B.	M	30	P	X		X			2		X			X							X							
S.B.	M	13	PP		X	X			1			X		X														
J.B.	F	14	PP	X		X			2			X		X										X				
De.B.	F	10	I		X	X			1			X																
Di.B.	F	14	PP		X		X		3			X		X														
D.C.	F	13	I	X		X			1			X	X											X				
J.C.	M	10	PP	X		X			1			X		X										X				
P.C.	M	23	PP	X					2	X				X										X				
L.C.	M	8	EXPIRED—NO SURGERY ATTEMPTED																										
R.C.	M	14	I		X	X			1	X			X																
S.C.	F	6	PP	X				X	1		X			X														X	*
P.De	F	8	PP	X		X			2		X		X																
R.D.	M	16	PP	X		X			2		X		X																*
M.D.	F	57	P	X			X		3		X			X	X						X								
C.F.	F	10	PP	X		X			2			X	X						X				X						*
J.F.	M	32	P	X		X			1	X				X															
L.G.	M	33	P	X		X			1			X		X															
I.G.	F	24	PP	X				X	1			X		X	EXPIRED — DAY 6, POST OPERATION													X	*
R.G.	M	19	PP	X			X		1	X				X															
H.H.	M	22	PP	X		X			1	X				X															
R.H.	F	37	LS	X			X		1					X															
T.H.	M	34	MS	X		X			1		X		X													X			
C.H.	F	55	F	X		X			2	X				X															
P.H.	F	18	I	X		X			1	X				X															
C.H.	F	14	I		X		X		2		X			X			X												
B.K.	M	22	P	X		X			1	X				X															
A.K.	F	18	I	X		X			1			X	X											X					
S.K.	F	20	PP	X		X			2			X		X										X					
L.L.	F	14	I	X		X			1		X		X											X					
M.M.	F	12	PP	X		X			1				X											X					*
D.R.	M	24	PP	X		X			3			X		X										X					
M.R.	F	15	PP		X	X			1			X		X										X					
D.R.	F	35	PP	X		X			2		X		X											X					*
A.R.	F	19	PP		X	X			1					X										X					
B.R.	F	13	PP	X		X			2		X			X			X		X			X		X					
M.R.	F	11	PP	X		X			1		X			X										X					
R.J.	M	45	P	X		X			1		X			X										X					
O.P.	M	18	PP	X		X			1			X		X										X					
G.P.	F	14	PP	X	X		X		3			X					X	X	X										
E.P.	F	40	CH	X		X			2				X											X					
K.P.	M	9	PP		X	X			2			X	X											X					*
S.R.	F	15	PP	X		X			1		X			X										X					
F.P.	F	45	PP	X		X			1		X			X										X					
B.P.	F	14	I	X		X			1		X			X										X					
J.P.	F	20	P	X			X		1			X		X	X			X	X										
R.S.	F	17	I	X		X			1		X			X										X					
D.S.	M	18	PP		X	X			1					X									X	X					
A.S.	F	14	I	X	X	X			3			X	X						X	X									
B.S.	F	38	I	X		X			2		X			X										X					
N.S.	F	15	I	X		X			1			X	X											X					
B.S.	F	16	I	X		X			1		X		X											X					
W.S.	M	15	PP	X		X			1		X		X											X					
H.S.	M	35	PP	X			X		2			X		X										X					
G.S.	M	35	P	X		X			1			X		X															
H.S.	M	12	PP	X		X			2			X	X											X					
F.S.	M	20	PP	X		X			1			X		X										X					
B.S.	F	16	I	X		X			1		X			X			X							X					
B.S.	F	12	I	X		X			1			X	X											X					
D.S.	F	17	PP	X		X			1			X	X											X					
R.T.	M	22	SCH	X		X			1			X	X											X					
J.T.	M	20	P	X		X			1			X		X															
K.W.	F	18	I	X		X			1		X		X											X					
G.W.	M	15	PP	X		X			1			X	X											X					
P.W.	F	25	AMY	X		X			1			X	X											X					
S.W.	F	19	PP	X		X			1		X			X										X					
B.W.	M	15	CONG	X		X			1		X			X										X					
L.W.	M	23	PP	X		X			1		X			X															
				59	12	57	9	2	95	8	28	29	26	40	3	0	4	2	6	1	2	0	3	40	1	0	2	

DIAGNOSIS KEY

AMY.—AMYOTONIA
SCH.—SCHUERMANN DISEASE
M.S.—MARIE STRUMPELL
P.—PARAPLEGIC
PP.—POST POLIO
I.—IDIOPATHIC
CH.—CHARCOTS DISEASE
F.—FRACTURE (UNCOMPLICATED)
L.—LUMBO-SACRAL INSTABILITY
CONG.—CONGENITAL

This table represents the patients in Group III—1960. Fusion was performed at the initial correction with instrumentation. Casts were used more frequently. Postoperative management (immobilization) was prolonged. Instrument fracture and bone erosion were greatly reduced.

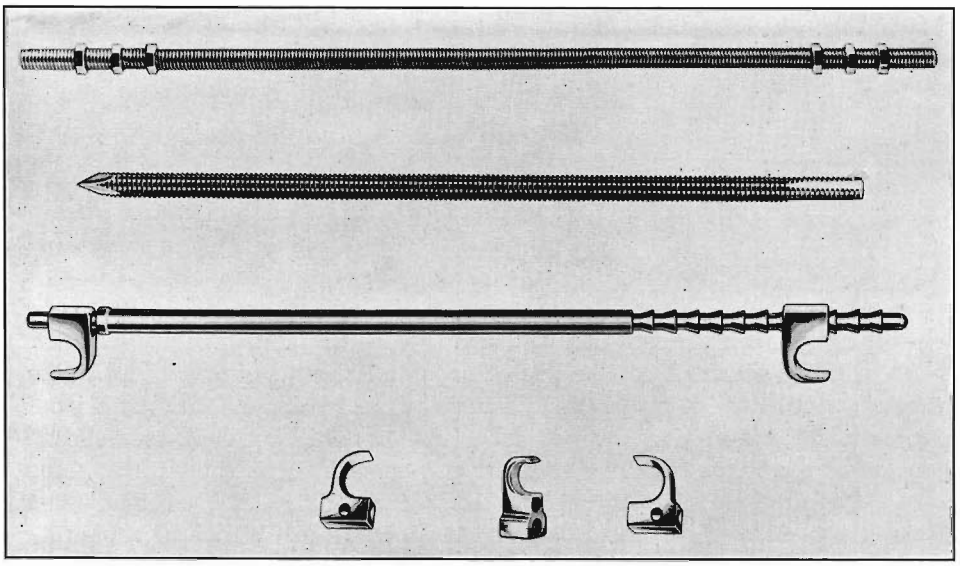

FIG. 1

The basic stainless-steel instruments used to apply compression and distraction forces to the spine. From top to bottom: a threaded rod for the compression system; a sacral bar; a distraction bar with purchasing hooks adjusted by the ratchet principle; and two compression hooks facing each other with a universal hook between them.

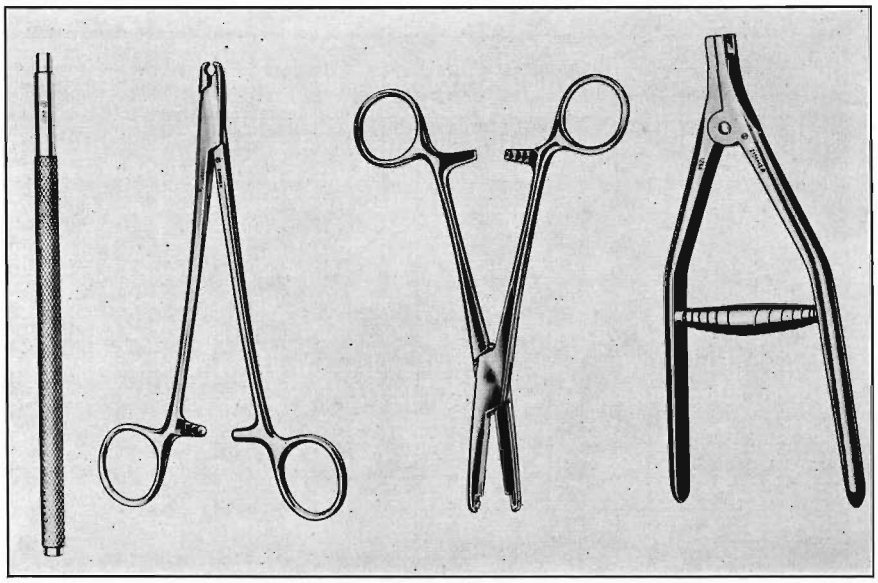

FIG. 2

The application instruments. These instruments are used to insert and to adjust the instrumentation once it is implanted. From left to right are a hook driver, threaded rod holder, hook holder, and spreader.

available. At the lower end of the rod, there is a reduced section three-quarters of an inch long which fits securely in the hole in the inferior hook. At the upper end of each rod there is a series of circumferential grooves so designed that the upper distraction hook will tilt slightly to engage on the shoulder of each groove and hence will not slip down the rod when axial compression is applied to the hooks. The rod therefore provides a ratchet system for progressive distraction of the two vertebrae engaged by the hooks at either end of the rod.

The hooks are one-half an inch thick and have a semicircular notch three-

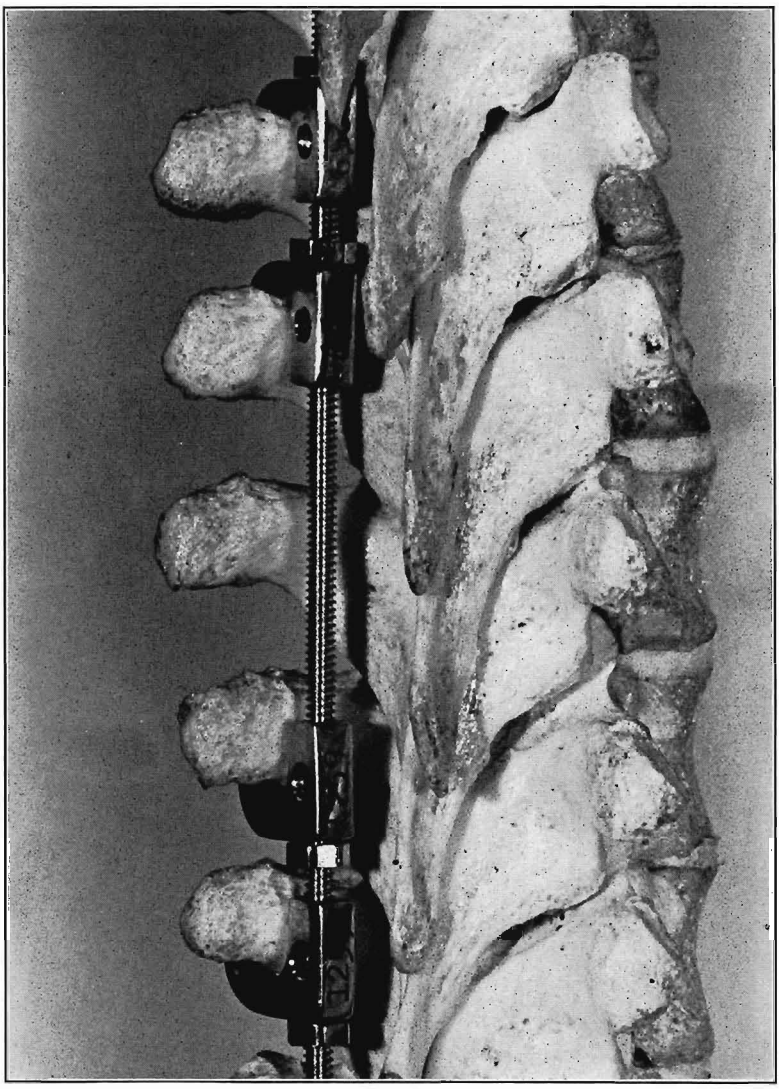

FIG. 3

A four-hook compression assembly properly placed at the base of the transverse processes of four thoracic vertebrae.

eighths of an inch in diameter. There is an axial hole through the hub of each hook; this hole will accept the reduced section of either end of the distraction rod. Another perforation at right angles to the axial hole accepts the stud on each jaw of the handling forceps and makes it possible to hold the hook firmly during insertion (Fig. 2). Within the axial hole of the large hook, there is a small shoulder which will slide over the circumferential ridges of the distraction rods, but which will also engage on the circumferential ridge when the distraction rod is under axial compression. The hook tilts somewhat and holds its engaged position.

The compression device, also of stainless steel (S Mo 18–8), consists of a threaded rod, hooks with axial holes into which the rod fits snugly, and hexagonal nuts of suitable size (Fig. 17). Two sizes of rods are provided, three-sixteenths of an inch and one-eighth of an inch in diameter, respectively. The larger rod is rigid; the smaller one is flexible and can be bent around a curve.

The sacral bar is a threaded rod one-quarter of an inch in diameter with one tip pointed for drilling purposes and a flat surface to prevent it from twisting out of

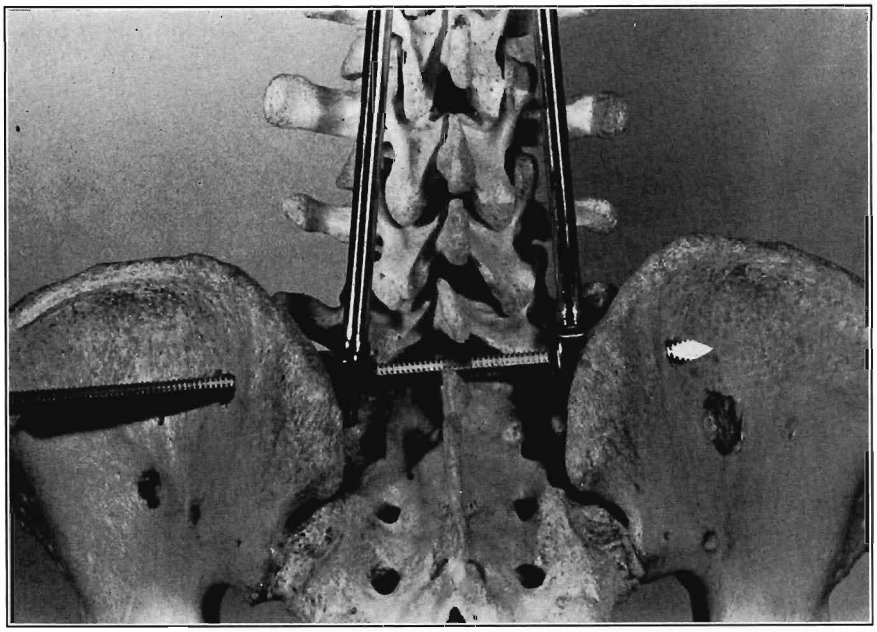

FIG. 4

A sacral bar with two distraction bars attached. Note the left purchasing hook has the hub posterior, whereas the right purchasing hook has the hub anterior. The flat surface on the threaded sacral bar is to prevent the bar from being rotated by the action of the purchasing hooks which are eccentrically loaded by the distraction bars.

FIG. 5

Schematic representation of the use of a universal hook in the supplementary instrumentation system.

the bone (Fig. 4). Universal hooks are used when a distraction force is to be applied to one curve and a compression force to the adjacent curve on the same side, both forces being applied to the same vertebra (Figs. 5 and 15-B).

The instruments used to hold and manipulate the apparatus (Fig. 2) include a hook driver, a threaded rod holder, a hook holder, and a force-applying spreader.

The manner of application of the device depends in large measure on the location, extent, flexibility, and other individual characteristics of the scoliotic curve to be corrected. The apparatus described may be used for any curve between the first thoracic segment and the sacrum. Either distraction, compression, or both may be applied. The eight-inch distraction rods of the device have a yield point of approximately 400 pounds on axial loading and over 200 pounds on eccentric loading. The actual force which may be applied to a spine is limited not so much by the strength of the device as by the strength of the bone into which or on which the hooks are set. The hooks may be attached to either the laminae,

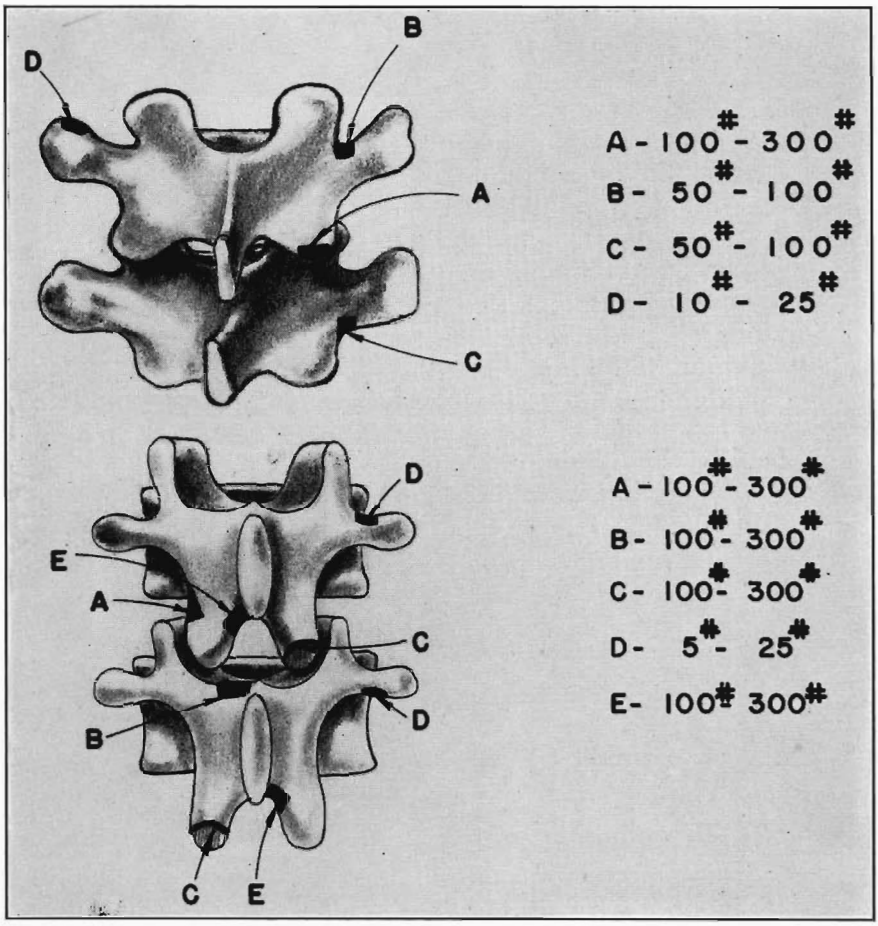

FIG. 6

The purchase sites in the thoracic (above) and lumbar (below) vertebrae used when applying the metallic system for compression or distraction.

transverse processes, or articular processes. These portions of the vertebra have a wide range of strength. The actual amount of force which they can withstand varies between twenty and 300 pounds. In Figure 6, the usual sites of application of the hooks are illustrated with the ranges of compressive and distractional force which each will tolerate. These ranges were established by a dynamometer gauge attached to the force-applying spreader. The values given indicate the order of magnitude of the mechanical strength of those sites where the hooks may be placed. In a given patient, there is no way to measure the load which can be tolerated by specific sites. The surgeon must estimate the degree of compression or distraction he is applying by feel and intelligent observation. Care should be taken not to reach the fracture point of the bone. Fracture of the bone at the site of application of a hook is catastrophic; therefore, the hooks should be carefully seated before correcting force is applied, and the correcting force should not exceed the yield point of the bone. When multiple hooks are used on one compression rod (Fig. 7-B), fracture of bone at one site may not be serious. In this situation, it is not necessary to reapply the hook at a new site, since the other hooks will suffice. The hook on the fractured bone may be left in place but no pressure should be applied to it. In our hands, fracture of bone at purchase sites is infrequent, and the desired pressure can be reached if the surgeon, by feel, applies small increments of pressure to the several purchase points in an orderly sequence

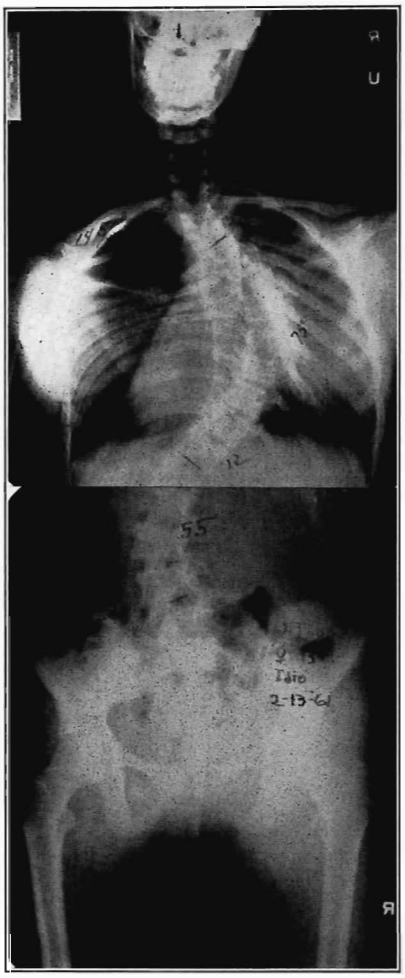

FIG. 7-A

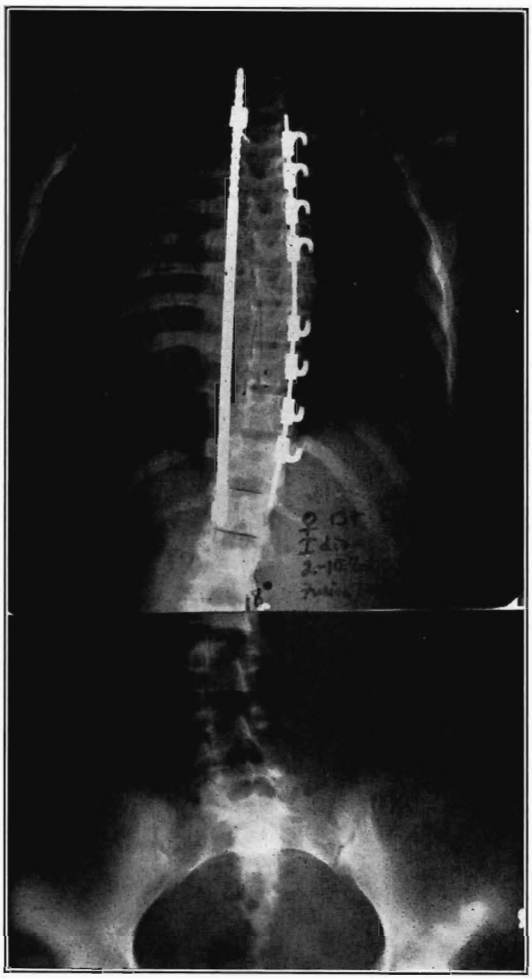

FIG. 7-B

Fig. 7-A: J. T. A standing roentgenogram of a thirteen-year-old white girl with an idiopathic right thoracic curvature measuring 75 degrees and a left lumbar curvature measuring 55 degrees. The Harrington factor (the degrees by the Cobb method divided by the number of vertebrae in the curve) was 8.3 for the thoracic curve and 10.5 for the lumbar curve.

Fig. 7-B: Roentgenogram of patient made in the supine position on the day of operation reveals a compression assembly of eight hooks and a distraction assembly of two hooks correcting the thoracic spine curvature of 75 degrees to 12 degrees. The spontaneous correction of the lumbar curve from 55 to 18 degrees is believed to be the result of altering the geometry of the spine as a whole.

until the combined forces in the whole system are brought to the desired level.

As the distraction force is applied, it encounters resistance from the soft tissues. After a few minutes of constant tension, the soft tissues stretch and more distraction can be achieved until the limit of the elasticity of the soft tissues is reached. When the normal elastic properties of the soft-tissue limits have been reached, a secondary tissue resistance is encountered. Elongation and deformation of this secondary resistance take place within twelve hours by tissue fatigue and microscopic rupture. When this occurs in the instrumentated spine, the abnormal forces which could cause erosion are non-existent. Resorption of bone under the stimulus of too much compression has not been a frequent complication in the recent cases where proper precautions were taken (Fig. 8).

The total force on the spine and on the apparatus is markedly increased by motion and by gravity. Although some erosion of bone is inevitable wherever bone is in contact with metal and under stress, excessive erosion is to be expected

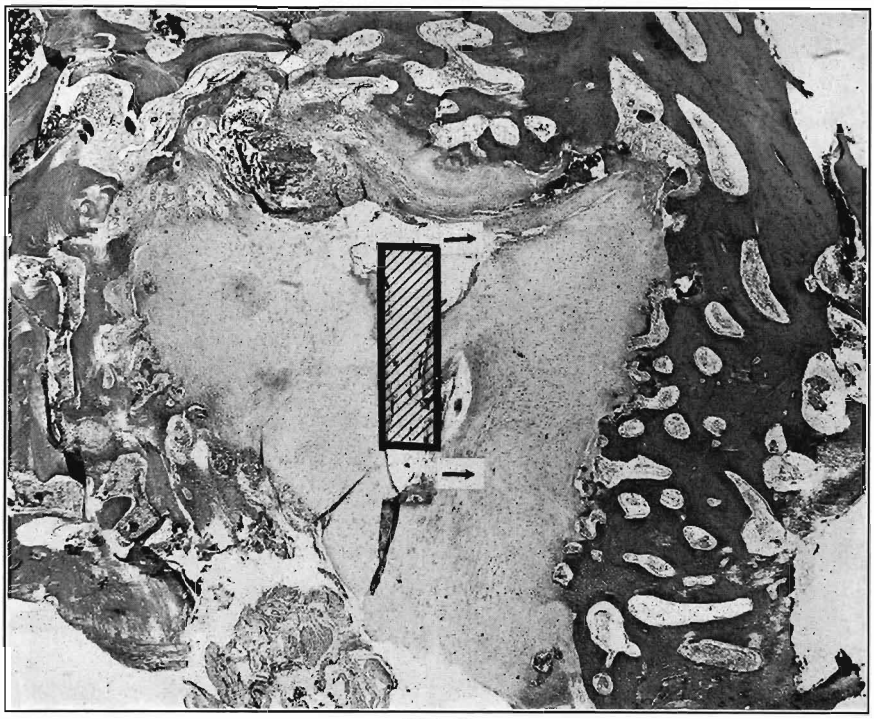

FIG. 8

Photomicrograph of section made through site from which a compression hook was removed six months after correction and fusion. The location of the hook is indicated by the rectangular shaded area; the direction of the pressure is shown by the arrows. Note fibrous tissue surrounding the location of the metallic implant and the increased density of the bone in the area subjected to pressure from the hook (hematoxylin and eosin, × 12.5). Histological studies of the implantation sites of the spine instruments in patients [9] demonstrated that the metallic device was walled off by the fibrous tissue reaction in six weeks, that new bone resembling callus was formed by ten weeks, and that mature firm bone was present by twelve weeks.

only when the stress is increased inordinately. In our patients between 5 and 15 degrees of correction was usually lost because of this erosion. However, if the patient assumed the erect position too soon after operation or moved his back excessively, more erosion occurred.

CLINICAL CONSIDERATIONS

The patients originally chosen for treatment by this new method were predominantly from a group of 3,000 patients with poliomyelitis, 400 of whom had scoliosis. A few patients with idiopathic scoliosis were also included in this early group. During the phase of the investigation ending in 1960, the method was applied to the treatment of scoliosis due to a variety of causes (Table III) and to the treatment of scoliosis of different degrees of severity in patients from four to forty years of age. Even the goal of treatment varied in this latter group. In several patients with amyotonia congenita and paraplegia so treated, the goal was to improve their sitting or standing endurance, whereas the goals of treatment in other patients were improvement of cardiorespiratory function, improvement in appearance, relief of pain, and the like. Because the clinical indications for therapy are still being worked out, they will not be discussed in detail at this time. However, several details in the selection of patients for treatment by this method deserve comment.

When a curve is progressing, I have found that the decision as to when to resort to surgical correction is simplified if a factor of my own devising is used (the

Harrington factor). This factor is determined by dividing the number of degrees of the primary curve, as determined by the Cobb method, by the number of vertebrae in the primary curve. If this factor is five or more, surgical treatment is usually indicated. Thus in the patient shown in Figures 7-A and 7-B, the preoperative factor for the thoracic curve was 8.3 (seventy-five divided by nine) and for the lumbar curve the factor was 11 (fifty-five divided by five), whereas after operation these factors were 1.2 and 3.6, respectively.

The significance of the Harrington factor varies with age. If the iliac epiphysis is still open and further growth of the spine will occur, a Harrington factor of five indicates that the curve will increase. In a young child with an increasing scoliosis and a Harrington factor of less than five and more than three, a Risser localizer jacket or Milwaukee brace will stop progression but rarely correct the deformity. If symmetry is maintained during growth, the spine will remain stable after maturity is reached.

In general, the following rules governing therapy are applicable when treatment with the device described is contemplated:

1. A Harrington factor of 5 or more should be present, with one or more of the following signs or symptoms: progression of the curve (in children); increasing pain or fatigue (in adults); and progressive cardiopulmonary decompensation.

2. The major curve and its transitional vertebrae should be identified on a roentgenogram made with the patient standing unsupported. The number of vertebrae, including the transitional vertebrae, is determined by the Cobb method.

3. The sites where primary and supplementary forces are to be applied are selected before operation. The primary forces, both distraction and compression, are applied to the primary curve. Distraction is applied to the concave side of the upper transitional vertebra or to the vertebra above this and to one or two vertebrae below the lower transitional vertebra. Compression is applied on the convex side to multiple vertebrae between the transitional vertebrae. Supplementary forces are applied to the lumbosacral spine according to the following rule:

Secondary forces are considered supplementary forces and are applied by the following rules relative 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:

1. 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 (the apex is over the base), the system will not need supplementation;

2. 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 (the apex is not over the base), the system will need supplementation.

SURGICAL PROCEDURE

This is an extensive procedure which is made possible only by modern surgical techniques and anesthesia. The limitations of the operation and the possible complications should be thoroughly discussed with all concerned before operation is undertaken.

Under endotracheal anesthesia, the patient is placed prone with the spine slightly flexed over lateral chest rolls. After suitable sterile preparation of the skin, the surgical field is covered with an adherent plastic drape; and, after the usual draping, the field is further sealed off with a plastic seal drape.

The usual exposure for spine fusion is carried out with special precautions

TABLE IV

BLOOD LOSS DURING SURGERY

(MEASURED IN CUBIC CENTIMETERS)

NAME	AGE	STAGE I	STAGE II	STAGE III	STAGE IV	STAGE V	SUCTION BOTTLE	TOT. BLOOD SALIVE	NORMAL SALIVE	TOTAL BLOOD LOSS
P.H.	14	24	212	101	96	128	460	1021	230	791
S.P.	14	10	205	248	0	105	362	930	350	580
P.C.	15	28	192	102	0	56	225	603	58	545
P.N.	15	12	172	100	0	57	485	826	92	734
D.W.	15	13	68	112	48	112	350	703	454	249
J.C.	16	14	56	10	10	26	110	226	106	120
H.S.	16	28	100	45	0	50	462	685	200	485
K.K.	18	43	164	67	0	38	273	585	195	390
K.S.	18	10	110	26	0	140	50	336	30	306
L.S.	19	46	484	196	76	85	1260	2147	710	1437
C.F.	19	20	243	132	116	26	860	1147	182	1265
P.F.	20	16	492	218	48	56	900	1730	0	1730
L.R.	20	20	260	162	30	261	720	1453	330	1123
V.H.	23	70	290	614	92	260	660	1986	341	1645
K.A.	25	56	175	74	34	40	664	1043	40	1003
P.L.	25	24	120	60	36	126	375	741	298	443
R.B.	26	80	295	215	0	38	550	1178	80	1098
D.C.	28	56	400	278	34	80	930	1778	670	1108
J.W.	33	22	174	88	48	36	600	968	648	320
R.A.	35	5	165	276	32	38	800	1236	610	626
D.K.	38	14	193	75	48	0	490	820	100	720
C.A.	39	24	277	288	745	208	1050	2582	498	2084
J.T.	40	20	174	68	43	54	270	629	114	515
B.T.	40	17	202	97	47	0	630	993	127	866
AVERAGES		28cc	217cc	152cc	66cc	86cc	564cc	1308cc	271cc	840cc

This table describes the blood loss in cubic centimeters recorded in the five stages of spine instrumentation and fusion on twenty-five consecutive patients. These cases are arranged in order of age to allow age correlation at a glance. Stage I is skin to periosteal dissection. Stage II is subperiosteal exposure of the intended operative site. The minimum exposure was ten vertebrae; the maximum was fourteen. Stage III is instrument application. Stage IV is spine fusion. Stage V is closure of the operative site.

to minimize blood loss. In the thoracic region, the exposure is carried out to the tips of the transverse processes; in the lumbar region the articular processes are fully exposed. By careful subperiosteal dissection, which proceeds beneath the capsule of each right and left posterior articulation, the arteries, veins, and nerves to the paraspinal muscles that emerge through the notch caudad to the inferior articular process of each vertebra can be spared.

Periodically throughout the procedure, the sponges are weighed to determine blood loss and the loss replaced by transfusion. The blood loss recorded in the operations performed has ranged from 200 to 2,000 milliliters (Table IV).

After the exposure is completed the sites for the placement of the hooks are determined by identifying the anatomically unique characteristics of the posterior elements of the twelfth thoracic vertebra. The site for the superior distraction hook is prepared by fashioning a notch (Figs. 9-A and 9-B) in the tip of the inferior articular process of the chosen vertebra. The inferior distraction hook is always seated in a lumber vertebra; the notch for this hook is made through the lamina where it meets the base of the inferior articular process (Figs. 10 and 11). After the notch has been prepared, a one-quarter-inch straight osteotome which is directed caudally and medially is driven through the inferior facet into the corresponding superior articular process of the vertebra below. After the notch has been thus prepared, the hook attached to the driver is driven in at such an angle that its tip enters the superior articular process and the rest of the hook is lodged between the superior and inferior articular processes. If the inferior articular process does not appear to be adequate to hold the hook, a notch can be prepared in the superior border of the lamina just lateral to the base of the spinous process. When this site is used care must be taken not to injure the dura.

Once the hooks for the distraction apparatus are in place, the previously

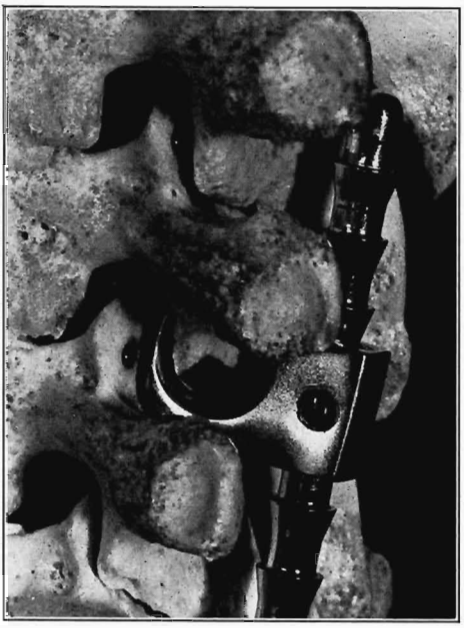

FIG. 9-A

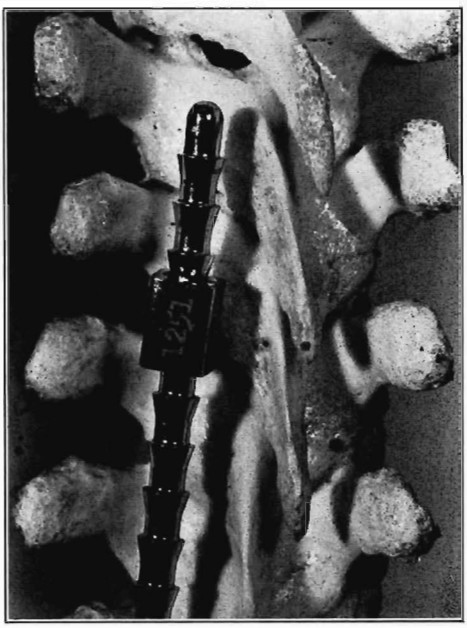

FIG. 9-B

Fig. 9-A: Lateral view of several thoracic vertebral segments showing the relationship of the upper distraction hook, the ratchet rod, and the articular processes where they are engaged. The notch of the hook is inserted into the margin of the inferior articular process in the black shaded area within the notch of the hook in this picture.

Fig. 9-B: Posterior view of the upper distraction hook and ratchet rod in position on the thoracic spine.

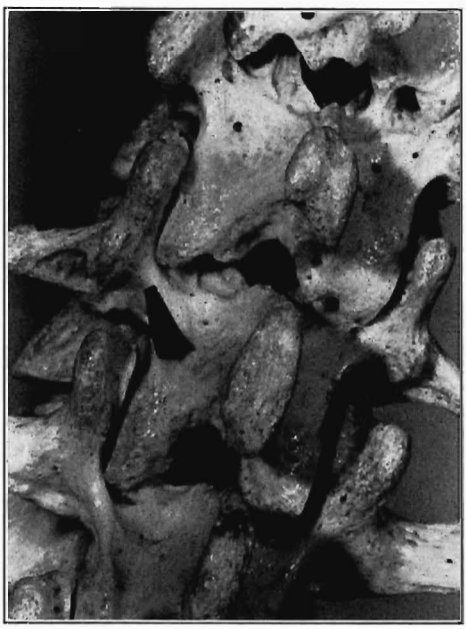

FIG. 10

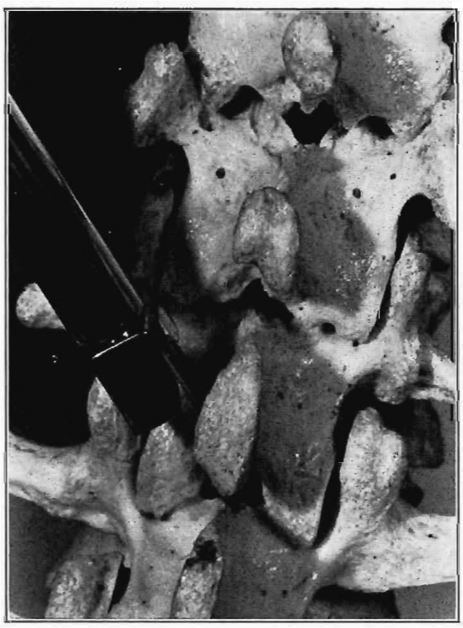

FIG. 11

Fig. 10: Posterior view of the lumbar spine to show location of the osteotomy that is made in the posterior cortex of the inferior articular process to allow insertion of the lower distraction hook.

Fig. 11: Posterior view of the lumbar spine and distraction hook on a driver showing the direction in which the hook is driven into the previously prepared notch (Fig. 10) in the inferior articular process. It is essential that the hook be driven in at the proper angle.

selected sites for the compression hooks are prepared. Each hook is held rigidly in the hook holder and dissected into place around the base of the appropriate transverse process as close to the pedicle as possible. The sharp edge of the hook makes it possible to dissect the costotransverse ligament off the bone as the hook is worked into place. Once in place, the hook holder is removed and the hook is left *in situ* for orientation when the compression assembly is inserted. At the caudad end of the compression system, the hooks are frequently on lumbar vertebrae. Here the hooks are inserted under the laminal arch or under the tip of the inferior articular process of the vertebra selected. A hook is never placed in a lamina directly over the spinal canal except below the level of the second lumbar vertebra because of the risk of penetration of the dura in the region of the caudal extremity of the spinal cord. When all the compression hooks are in place, a compression rod with nuts and hooks at the appropriate levels is assembled (Fig. 3) using the large rigid or small flexible rod as indicated. Starting at the top, the previously placed orientation hooks are removed, and the hooks on the compression assembly are inserted serially. At first this procedure may prove difficult. If the direction of insertion of the previously placed orientation hooks is kept in mind, the procedure is simplified. When the hooks on the rod are introduced they should be kept in exactly the same position as the orientation hooks. Also if the hooks used for orientation are inserted several times first, it is easier to place the less easily adjusted hooks that are on the rod. During insertion of the compression assembly each hook is held by the holder while the threaded rod is held in the holder designed for this purpose (Fig. 2). The rod holder is particularly useful to hold the assembly after the upper hooks have been placed and the lower hooks are being put in position. It is most disconcerting to work a set of hooks into place only to find that they have slipped out during the placement of other hooks. With a little planning before the compression assembly is inserted and practice the procedure is not difficult. Initially an assembly with two or four hooks should be used. Once the insertion of such an assembly is learned, the reward of the greater correction and stability afforded by multiple hooks is too attractive not to invite the use of the maximum number of compression hooks on every compression assembly that is inserted.

As soon as the compression apparatus is in place, the hooks are moved to the tight position by advancing the hexagonal nuts. At this point the wound is irrigated and the placement of all apparatus reviewed prior to the most gratifying phase of the operation, the application of the corrective forces.

The first step is to prepare for the application of the distraction force. This is done by threading a distraction rod of proper length through the hole in the previously placed superior hook in a cephalad direction until the inferior end of the rod engages the lower distraction hook. As this is done it should be noted if the rod will block access to the posterior articulations on the concave side of the curve. If it appears that these joints will be covered by the rod and spine fusion is thought indicated, a fusion of the facet-block type [13] is performed on this side before the rod is placed. The articular surfaces are gouged out and grafts from the spinous processes are placed in the defects so created. The fusion procedure completed, the lower end of the ratchet rod is firmly seated in the lower hook and distraction is applied using the spreader (Fig. 2). The curve is corrected slowly, one notch at a time. In doing this the surgeon must develop a sense of the proper amount of force to be applied; and, as distraction is accomplished, he must observe the hooks to make sure that they do not slide before they become firmly seated. Once well seated, they do not as a rule slide if the upper ratchet hook has been well seated. However, if shifting or sliding does take place, a loop of wire is placed

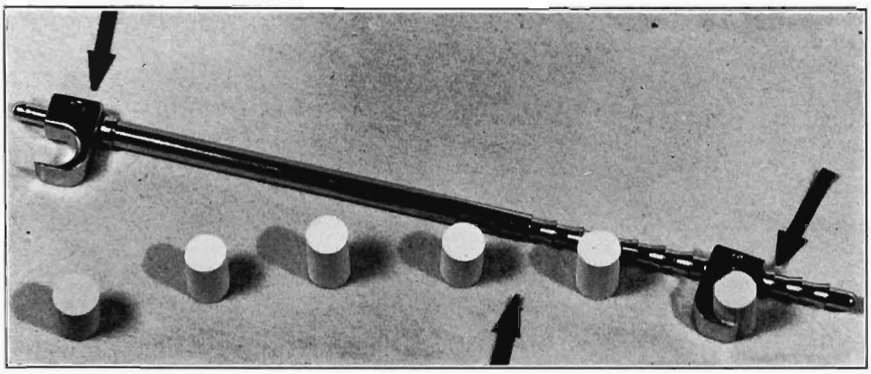

FIG. 12

Schematic representation of the distraction assembly being applied to a kyphotic deformity. The white cylinders represent ribs; the arrows indicate the forces involved in the placement of the assembly in proper position.

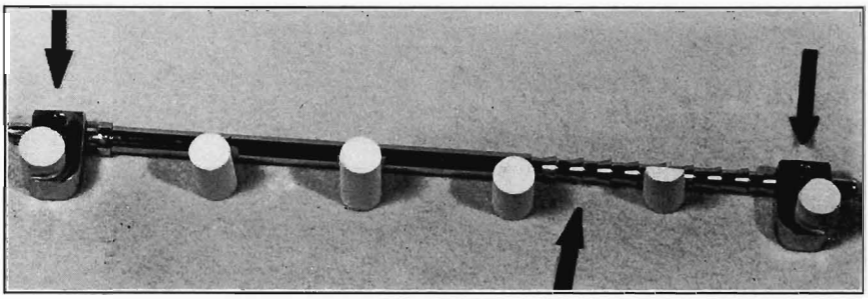

FIG. 13

Schematic representation of the distraction assembly in place on a spine with a kyphotic deformity (compare with Fig. 12). The assembly is manipulated into the correct position by springing it downward and engaging both hooks or, if need be, by osteotomy (as indicated by the half cylinder) of one or more ribs to provide room to displace the rod forward bringing the hooks into the desired position.

around the hook and corresponding spinous process to prevent further displacement. The lower distraction hook is particularly prone to slide and should be watched closely. This is the weakest feature of the whole procedure. A new device is being designed to provide a more secure purchase on the lumbar articular process. It should be noted here that an apparently insurmountable problem may arise during the placement of the distraction rod in severe scoliosis with some kyphosis. Here the deformed ribs at the apex of the curve on the concave side may hold the lower end of the distraction rod several inches away from the inferior hook as the rod is inserted through the upper hook (Fig. 12). One possible solution to this problem is to lever the rod down over the ribs once the upper ratchet hook has been well seated. However, if the upper hook is not seated firmly or if the force applied is too great, the facet and lamina in which the upper hook is engaged may break as the surgeon attempts to pass the rod through the hole in the caudad hook. The anesthetist can often help by lifting the head and shoulders of the patient until the rod has been inserted into the hole in the inferior hook and the distraction force adjusted. If difficulty is still encountered, osteotomy of one or two of the prominent ribs can be done (Fig. 13). Another way to overcome this difficulty in a severely scoliotic patient is to start with a short distraction apparatus near the apex of the curve and then introduce a second longer distraction system once the initial one is well seated and the curve partially corrected.

The distraction and compression systems are tightened gradually in orderly sequence until both mechanisms are tight. The wound is then irrigated; and the

FIG. 14-A

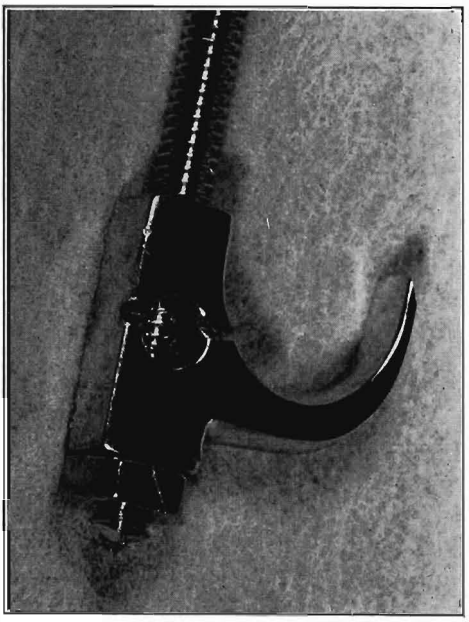

FIG. 14-B

Fig. 14-A: Distraction hook and ratchet rod showing locking wire in place.
Fig. 14-B: Photograph of compression hook and threaded rod after the hook has been crimped and the rod has been cut close to the hexagonal nut to lock the hook in position.

patient's trunk is twisted and shifted from side to side, and the moderately flexed table is straightened. After several minutes have passed, the entire mechanism is readjusted. Care must be taken at this point not to fracture any of the sites of purchase. When the system is found to stay tight, the operator attempts no further correction. At this point all the assembly hooks are locked by crimping the hooks of the compression assembly (Fig. 14-A) and by using a loop of wire to lock the ratchet of the distraction device (Fig. 14-B).

The surgeon must now decide whether spine fusion is to be performed to supplement the instrumentation. If the patient's condition will withstand the additional surgical procedure and if a fusion has been contemplated preoperatively, a Hibbs type of fusion should be done. If it is decided not to fuse the spine at this time, the wound is closed.

If supplementary stabilizing forces are necessary, as indicated by the presence of an obtuse sacral angle, as previously described, the sacral bar and distraction rods are introduced. These supplementary forces are not corrective but are used to hold the lower spinal segments in a stable position (Fig. 4). The lumbosacral junction should always be exposed well to allow a three-dimensional visualization of the region as the sacral bar is introduced through a stab wound in one buttock. The sacral bar is inserted with a motor-driven drill. The sharp point of the bar makes it possible to insert it accurately in the uneven inclined surface of the ilium; and the threads of the bar advance it in the proper line, preventing any shift in the direction of the bar once it is introduced. There is a flat side on the sacral bar to prevent torsional working caused by the hook of the distraction apparatus. The application of the sacral bar and its relation to the distraction bars which are attached to it are illustrated in Figure 4.

A universal hook is used, as already described, when overlapping distraction and either a compression or a stabilizing force are needed. The overlap of the two devices must extend for at least four vertebrae or the spine with the attached

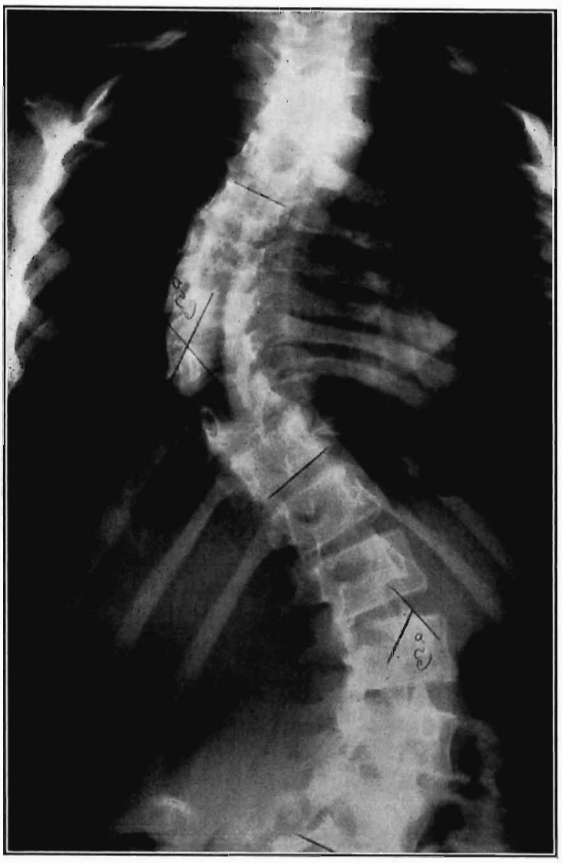

FIG. 15-A

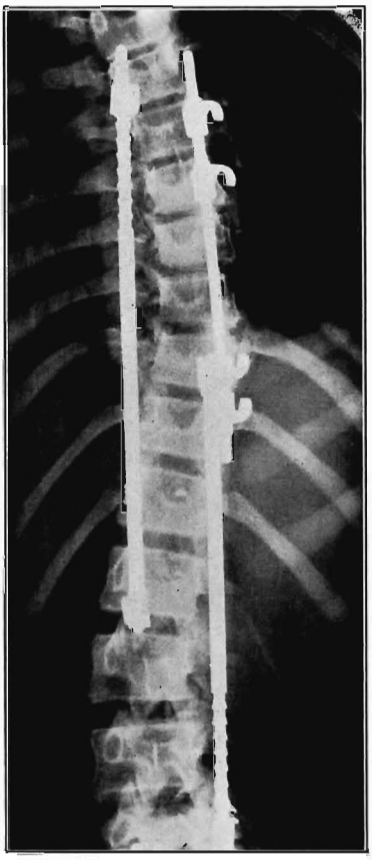

FIG. 15-B

Fig. 15-A: L.L. Postero-anterior roentgenogram of a right thoracic left lumbar idiopathic scoliosis in a girl, thirteen years old. The thoracic curve is 65 degrees and the lumbar curve is 65 degrees as measured by the Cobb method.

Fig. 15-B: Postero-anterior roentgenogram after correction by spine instrumentation using compression and distraction assemblies on the thoracic curve and a distraction device on the lumbar curve with overlapping of the compression and distraction devices on the right side of the spine accomplished by means of a universal hook. Spine fusion was performed from the fifth thoracic to the fourth lumbar vertebra.

apparatus will buckle posteriorly at this point. In a paralytic spine, more extensive instrumentation must be used to prevent tilting of the spine at the upper or lower end of the apparatus.

At the conclusion of the operation, an elastic adhesive compression bandage, laminated over foam rubber (one-half of an inch by three inches by the length of the wound), is applied and left in place for at least five days. A roentgenogram is obtained and the patient is kept supine for six hours; he may then be gently logrolled to either side at regular intervals. This is the patient's only activity until the tenth to fourteenth day, when the sutures are removed and a well molded plaster body cast is applied. After a few days of adjusting the cast, the patient is sent home. Recumbent posture is maintained with logrolling for an additional six to eight weeks. The patient is then allowed to stand and walk for a few minutes in his cast, maintaining erect posture, three times a day. Sitting is not permitted. The activity time is doubled at five-day intervals until a period of forty minutes of walking and standing three times a day is reached. The patient may then sit for meals and toilet necessities and start walking half a mile three times a day. A roentgenogram of the spine with the patient standing in the cast is obtained in the anteroposterior plane and compared with the immediate postoperative

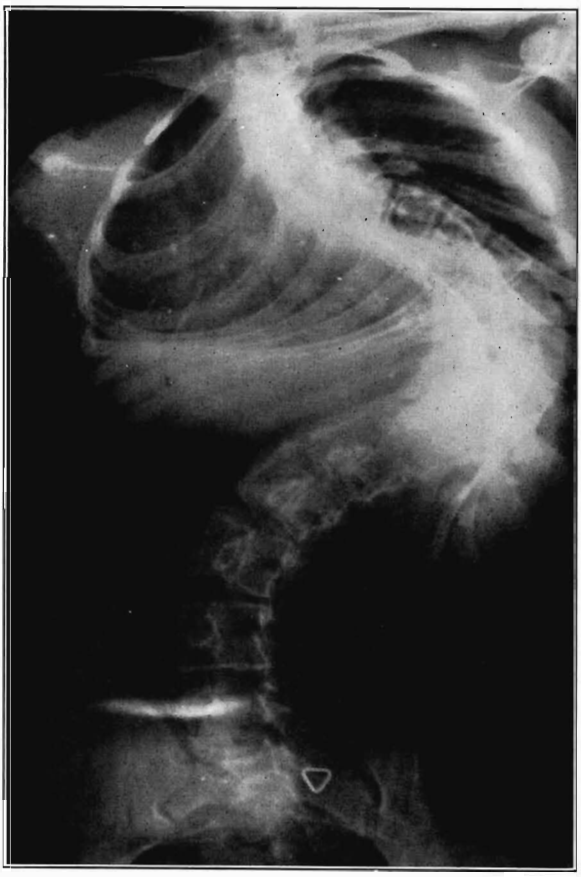

FIG. 16-A

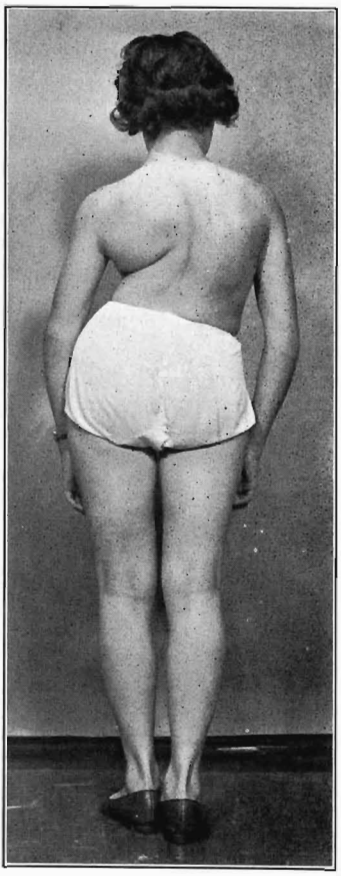

FIG. 16-B

Fig. 16-A: C.B. Postero-anterior roentgenogram of a severe idiopathic curve in a girl, fifteen years old.

Fig. 16-B: Preoperative photograph made in 1958.

roentgenogram. If more than 10 degrees of correction is lost, the cast is kept on an additional month in patients under fifteen years of age. Patients from fifteen to twenty-five years of age wear the cast a minimum of four months; those from twenty-five to thirty-five, a minimum of five months, with reasonable activity as time progresses. After removal of a cast, restricted activity is allowed for three months and reasonable activity (no athletics or physical education) for an additional three months, when a roentgenogram should reveal the final results.

RESULTS

The purpose of this article is to describe a method for the treatment of scoliosis indicating how the method has been developed and improved rather than attempting to analyze the results obtained. The over-all results of the treatment of scoliosis can only be evaluated by considering many factors. In the present series with the many modifications of the apparatus introduced, the inevitable difficulties attendant upon the development of any new surgical procedure of this magnitude, and the variety of conditions treated, a true evaluation of the results is not as yet possible. Three illustrative cases are shown in Figures 7-A, 7-B, 15-A, 15-B, and 16-A through 16-G. The results were graded roughly according to the following system.

The patient was considered *better* if the curve was decreased; if progression of the curve in a child was arrested; if function was improved (improved tolerance

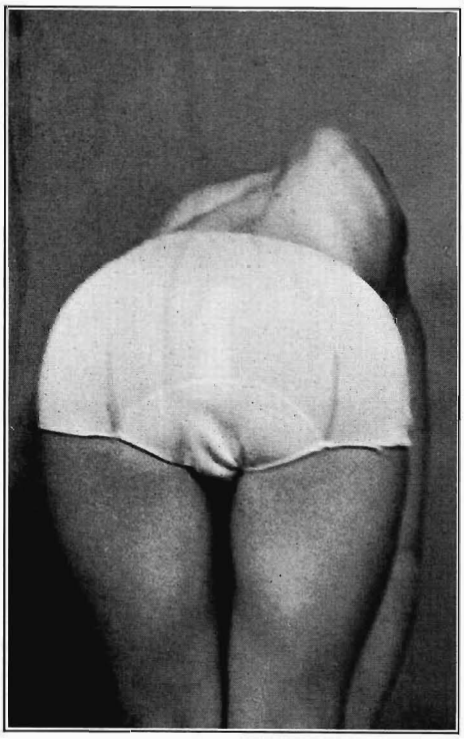

FIG. 16-C

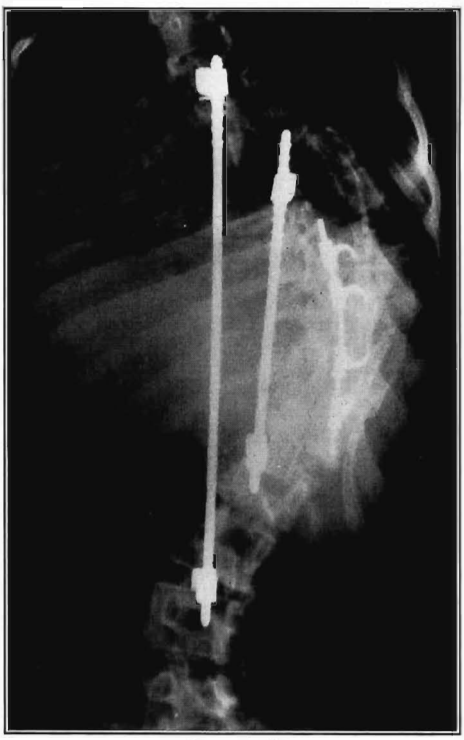

FIG. 16-D

Fig. 16-C: Preoperative photograph of the sabre-back deformity in flexion.
Fig. 16-D: Postero-anterior roentgenogram made in 1958 after correction by instrumentation and spine fusion. The patient was supported in a body jacket after operation, and in 1959 a rib resection was performed.

FIG. 16-E

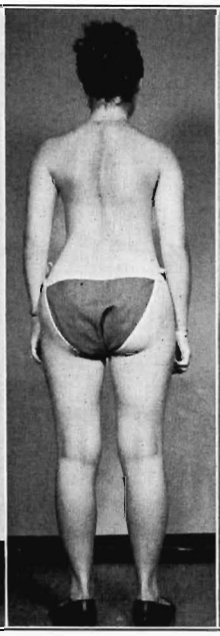

FIG. 16-F

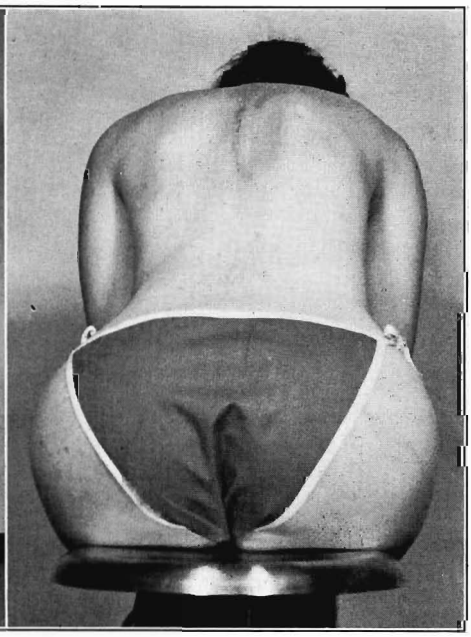

FIG. 16-G

Fig. 16-E: Photograph made in 1958, twelve days after operation.
Fig. 16-F: Standing photograph made in 1960.
Fig. 16-G: Photograph made with the patient sitting in flexion to show residual back deformity.

for activities of living and decreased instability of the back); if fatigue, pain, and respiratory distress were reduced; and if the psychosocial effects of the deformity were reduced.

The patient was rated the *same* if some of the aforementioned benefits were realized but they were offset by persistent imbalance, lack of functional improvement, persistence of fatigue, and so forth.

The patient was judged *worse* if secondary curves developed requiring repeated surgical procedures or if there was failure of the apparatus, bone erosion, or progression of the secondary curves. Also included in this category were the two patients who died.

TABLE V

GROUP I–II–III

	CASES	AVERAGE OPERATIONS	FUSION	NO FUSION	INSTRUMENT FRACTURE	ERO-SION	BET-TER	SAME	WORSE
GROUP I	19	3.0	12	5	11 58%	10 52%	11 58%	5 26%	3 16%
GROUP II	42	2.4	30	12	14 33%	22 52%	25 59%	9 21%	8 20%
GROUP III	68	1.3	58	10	2 3%	4 6%	57 84%	9 13%	2 3%

This table correlates the pertinent results in all three study groups. It reveals that spine fusion combined with instrumentation and prolonged immobilization in a plaster jacket (Group III) gave better results than those obtained with no cast and no immobilization in Groups I and II. The results indicate that spine instrumentation is a useful tool in the treatment of spine instability.

The results graded according to this system during the different phases of the development of the apparatus are indicated along with the complications in Tables I, II, and III. The over-all trend of the results is shown in Table V. The legend of Table V explains the advantage of initial fusion and postoperative cast immobilization.

The complications encountered in the patients treated so far are also indicated in the tables, but they deserve special mention. Two deaths occurred in the total series of 129 cases, the first due to obstructive bronchial edema four hours after intubation, the second six days after operation as a consequence of cardiac failure and cor pulmonale of nine months' duration. Breakage of the bar occurred in eleven of the first nineteen patients (Table I). With the redesigning of the instrument, breakage occurred in four of the forty-six patients in the second series (Table II); with the bars as now made, there were only two instances of breakage in the last fifty-nine patients. The other complications are also listed in the tables; they include pseudarthrosis after attempted fusion, dislocation of the hooks, radiculitis, progression of the secondary curve, and bone erosion at the site of purchase of the hooks. Some of these complications might be expected with this type of treatment; others might occur with any type of surgical treatment of scoliosis.

DISCUSSION

The results in the three groups show a gratifying improvement associated with increasing experience and refinement of the apparatus. With the newer apparatus and longer periods of immobilization after operation, the incidence of complications and instrument failure have been markedly reduced. It is significant that in the last group, spine fusion at the time of spine instrumentation was performed more frequently.

On the basis of my experience to date, I believe that a progressive scoliosis in a child less than ten years old can be managed with the apparatus alone

without fusion, whereas in a child more than ten years old fusion should usually be done at the time of the initial correction. No form of treatment including the method described here with or without spine fusion can be considered definitive in a child whose axial skeleton is still growing.

The techniques, criteria for use, and the problems of metallic instrumentation of the malformed or unstable axial skeleton have been presented. Results have been given in table form by recording a simple classification of the results and the frequency of observed complications. The general conclusions from experience in the use of this surgical method in 129 patients over a period of eight years are:

1. The axial skeleton can be gratifyingly corrected from a malformed state in a growing child and adult by a prestressed metallic system in direct contact with it;

2. The axial skeleton can be stabilized by a prestressed metallic system in direct contact with it, especially if spine fusion is performed within the span of the instrumentation;

3. Metal (S Mo 18–8) is tolerated in the body and can be used in direct contact with the axial skeleton for a reasonable length of time (one to five years);

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

5. 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 remaining. A well molded plaster-of-Paris body cast should be applied after surgery for twelve weeks or longer in almost all cases.

Complications occur, but they are correctable and have been minimized with time through changes in design, alterations of postoperative immobilization, and 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 (four to forty years), etiology (paresis, idiopathic, or congenital), 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.

SUMMARY

A new method for the treatment of scoliosis is described in which a metal system of rods and hooks is implanted, and distraction and compression forces applied, to correct the curve and stabilize the treated segments in the corrected position by skeletal fixation. The technique and principles of this method of treatment and a summary of the preliminary results obtained are given.

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(Continued on page 634)