PARALYTIC SCOLIOSIS

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A study of the sparse literature on paralytic scoliosis shows how little we know of this deformity. The differentiation of paralytic scoliosis into patterns, and the prognosis, are hardly mentioned. It seems that this deformity, like those seen elsewhere after poliomyelitis, is produced by unequal muscle pull. This has more often been stated than proved. Colonna and Vom Saal (1941) reviewed 500 cases of poliomyelitis including 150 with paralytic scoliosis. They attempted to correlate muscle paralysis with the type of curvature that developed. The evidence to be presented in this contribution will, it is believed, show that most of their conclusions are incorrect although some are confirmed. I would however like to pay tribute to these authors as the originators of important principles relating to the development of paralytic scoliosis.

A series of 193 patients with paralytic scoliosis has been studied. The aim was to classify the scolioses into groups based on their anatomical site, to discover the prognosis, and to correlate the associated muscle paralysis with each. In addition, a group of 280 patients with poliomyelitis but without scoliosis has been studied. Children with an average of seven years from the onset of disease showed frequent asymmetrical paralysis of limb muscles but no curvature of the spine.

In idiopathic scoliosis the division into groups based on the anatomical site of the primary curve has considerably advanced our understanding. A rather similar group of curve patterns exists in paralytic scoliosis. However, these groupings are not clear-cut, nor is each group homogeneous within itself. This is not surprising because the degree of muscle imbalance and the age at which paralysis occurred are more important prognostic features than the anatomical situation of the primary curve, whereas in idiopathic scoliosis the site of the primary curve is the main determinant of prognosis.

It is not difficult to decide which of the curves is the primary one. The distinction between a primary and compensatory curve is largely clinical, and relies on the fact that fixed structural rotation persisting on forward flexion occurs only in primary curves—this being more strictly true of paralytic than of idiopathic curves.

Arm and leg muscles that might be related to scoliosis have been charted, using the Medical Research Council grading 0–5. It would appear that paralysis of these muscles is not related to the development of scoliosis. Colonna and Vom Saal recorded only the number of occasions on which certain muscles were found to be paralysed in relation to the concavity of a curve—for example the trapezius in thoracic curves. In this series limb muscles paralysed on both sides were studied, and the numbers were found to be approximately equal.

In the trunk a relationship between muscle weakness and scoliosis has been found, but not that which has commonly been accepted. In brief, weakness of the mid-line muscles such as the erector spinae and the anterior abdominals cannot be shown to have any statistical relationship to the development of lateral curvature, though they are related to antero-posterior deformities. Symmetrical weakness of these muscles causes a collapse of the spine and thus a non-structural lateral curve. It is highly probable that this collapse is in part the cause of structural lateral curvatures of the spine.

The lateral trunk muscles—the intercostals, lateral abdominal muscles and to a small extent the latissimus dorsi—do however bear a very interesting relationship, being weak on the convexity in a highly significant number of patients. These muscles act on the spine through the long levers of the ribs and it would appear that this is an important factor.

These conclusions must be studied with the reservation that paralysis of the trunk muscles cannot be graded exactly. To reduce this source of error I have so far as possible done the charting myself. Fortunately, it is the asymmetry of right and left muscles that is important and this is often easy to determine, though the quantitative interpretation in terms of the Medical Research Council grading is not always reliable even with one observer. As this study is largely dependent on accurate muscle charting, a brief account will be given of the method as applied to the muscles which present special difficulty in assessment—the intercostals, erector spinae and the anterior and lateral abdominals.

Intercostal muscles—This study of the intercostal muscles was instigated by the development of a high thoracic curve in a patient who was known to have had poliomyelitis. This is the only cause of this type of curvature except congenital lesions and yet careful muscle charting revealed no abnormality. On the third study of this patient's muscles it was found that the apex of the chest on the side of the curve did not expand at all, in marked contrast to the other side.

The strength of the intercostal muscles is now measured at three levels. At the apices both hands are placed palm down, and their upward and forward excursions are compared. At the nipple line and the bases the fingers encircle each side as completely as possible while the thumbs touch one another anteriorly; the degree of excursion of each thumb on inspiration is noted. The correlation of the excursion with the Medical Research Council grading is most inexact and personal, but asymmetrical expansion is seen and felt quite easily and is found consistently; one hand may remain still while the other moves from one to one and a half inches. Of course, the accessory muscles of respiration must be relaxed.

Erector spinae muscles—It is always difficult or even impossible to detect minor localised weakness of the erector spinae muscles on one side as compared with the other, and this is especially so in scoliosis. Thus chartings here record the performance of both erectores spinae together and in their whole length. Study of the erector spinae over the length of the primary curve at operation often failed to reveal diminution or pallor of either muscle.

Anterior abdominal muscles—Orthodox examination of the anterior abdominal muscles has presented little difficulty. The movements of the umbilicus (Beever's sign) are a sensitive indicator of abdominal asymmetry. Vertical asymmetry is not recorded here.

Lateral abdominal flexor muscles—This group, comprising quadratus lumborum and the lateral part of the abdominals, is difficult to assess. The patient is told to elevate the pelvis on one side while the leg is pulled downwards. The measurement of strength of these muscles is aided by placing a hand between the iliac crest and the ribs which are approximated by true action of these muscles but not by trick action of latissimus dorsi, the erector spinae on the concavity, nor by wriggling movements using the gluteal muscles. Visually this trick movement is not easily detected. It is important to make sure that lateral active flexion is not prevented by lumbar stiffness.

CURVE PATTERNS IN PARALYTIC SCOLIOSIS

The following curve patterns are regarded as distinct; they are similar to, but not identical with, those of idiopathic scoliosis. The numbers refer to the cases available for study; they total 193 patients.

Curve patterns			
High thoracic.	.	.	39
Thoracic	.	.	69
Thoraco-lumbar	.	.	47
Lumbar.	.	.	17
Combined thoracic and lumbar	.	.	13
"Telescopic" spine	.	.	8

These patterns will be studied particularly in relation to the associated muscle paralyses and to the prognosis.

FIG. 1

High thoracic scoliosis. The right trapezius is elevated by the rotated upper ribs. The neck and head seem to be sidestepped on the trunk.

FIG. 2

High thoracic scoliosis with curvature of 120 degrees. The initial deformity is being disguised by the thoracic kyphosis and cervical lordosis.

HIGH THORACIC PARALYTIC SCOLIOSIS

I define this pattern as a primary curve in the upper thoracic region in which the highest vertebra of the primary curve is at the level of either the first thoracic (thirty-one cases) or second thoracic (seven cases). Only one curve extended into the cervical spine to the seventh cervical level.

This radiological definition is arbitrary, but early in this study it became apparent that there was a clinical type with an ominous prognosis and a most serious cosmetic effect. Rotation of the uppermost two ribs creates an elevation of the trapezius line of the neck. This is thrown into relief because the neck develops a compensatory curve in the opposite direction (Fig. 1). When the degree of curvature is great this may be disguised by the associated upper thoracic kyphosis, and by the compensatory cervical lordosis; the head then appears to be dropped between the shoulders (Fig. 2).

It is impossible to disguise this deformity by the dressmakers' art, unlike curves in other areas; even a collar and tie detracts little from the ugly deformity. It is to be remembered

FIG. 3

High thoracic scoliosis. Interval between poliomyelitis and onset of scoliosis (thirty-three patients).

that the obvious deformity arises from rotation of the ribs and is therefore unaltered by surgical fusion, which therefore should be early and prophylactic, rather than curative. Knowledge of the prognosis in this curve is the basis of our therapeutic decision.

Thirty-nine patients suffering from high thoracic paralytic scoliosis were studied. There were twenty-two females and seventeen males. The primary curve was convex to the right in twenty-one and to the left in eighteen.

The age at which poliomyelitis occurred is, of course, scattered through the years of childhood. The oldest child to develop poliomyelitis and then scoliosis was a boy of fourteen years nine months, with a final high thoracic curve of 30 degrees. Structural scoliosis did not follow poliomyelitis in adult life. The interval between poliomyelitis and the onset of this pattern of curvature was recorded in thirty-three patients; it varied between a few weeks to fifteen years, but in half of them it was noted within one year (Fig. 3).

The curves starting at the first thoracic level extended variably between the sixth and eleventh thoracic vertebrae, and those beginning at the second thoracic from the ninth thoracic to second lumbar. Thus there might be from six to thirteen vertebrae in the primary curve. The distribution between these extremes was even. This length of curve is on the average greater than the idiopathic variety in which curves of twelve and thirteen vertebrae (four cases) are never seen.

Prognosis—In twenty of the thirty-nine patients the iliac apophyses had reached the posterior superior spine. Risser has shown that this is contemporaneous with the end of spinal growth, after which an idiopathic curve will not increase. In paralytic scoliosis such an end-point is not absolutely reliable but a noteworthy increase after this event was very rare in this series. The complete development in length of the iliac apophysis will therefore be taken to indicate the completion of curvature.

Figure 4 illustrates the final curvature of the twenty adult patients. How commonly gross deformity arises is well seen. Mild curves may be radiographically defined as those of less than 70 degrees (four cases), severe 70–99 degrees (one case), very severe 100 degrees or more (fifteen cases). The worst curve seen amounted to 155 degrees.

Among the remaining nineteen patients at present under observation who have not completed growth, there are four very severe curvatures, nine severe and six mild; four of the latter group are less than ten years of age. Eleven of these nineteen have already been operated upon and their natural evolution has been interrupted. The prognosis of the high thoracic paralytic curves untreated or conservatively treated is indeed gloomy.

FIG. 4

High thoracic scoliosis. Twenty mature curves.

Colonna and Vom Saal came to the conclusion that "the upper extremity and the back muscles cause thoracic scoliosis." Their thesis was that the stronger arm muscles pulled the spine towards them. They investigated latissimus dorsi, trapezius and the rhomboids. They found latissimus dorsi to be paralysed thirty-four times out of sixty-four on the side of the concavity. The rhomboids they found to be weak on the concavity thirty-six times in forty-two cases and six times on the convexity, and in all twenty-eight cases of weak trapezius the affected side was the concavity of the curve. The deltoid was weak on the side of the convexity in twenty-three of forty-five cases. No statistics are given for the erector spinae. In their paper no information is available about the degree of muscle weakness present or of the existence of weak muscles on the convexity of the curve, and they did not discuss the existence of weak muscles without scoliosis.

In this series paralysis of the arm muscles is not thought to be significant; the commoner finding was weakness on the convexity, the opposite to that recorded by Colonna and Vom Saal. They did not mention the role of the intercostals, nor has any reference been made by any other author in a comparable manner. It is believed that it can be shown that the

intercostals on the convex side of the curve are the only muscles that are significantly paralysed. The intercostals exert through the ribs a very effective leverage in laterally flexing the spine. Before discussing the role of the intercostals it would be well to see the evidence on which this assertion is based.

Trunk muscles—In six patients the only weakness found was in the intercostals muscles; the curvatures in these cases were 127 degrees, 122 degrees, 100 degrees, 100 degrees, 81 degrees, 77 degrees; there is nothing here to suggest that other muscles play a part even in such severe curves.

Intercostals. High thoracic curves

Intercostal weakness towards the convexity	29
Intercostal weakness towards the concavity	0
Intercostals symmetrically weak (less than 2) or totally absent	5
Inadequate records	5
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	39

Erector spinae. High thoracic curves

Erector spinae grade 4 to normal	32
Erector spinae less than 4	6
No record	1
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	39

Lateral abdominal flexors. High thoracic curves

Lateral abdominal flexors. Symmetrical grade 4 to normal	26
Lateral abdominal flexors. Weakness on the convex side	4
Lateral abdominal flexors. Weakness on the concave side	5
No records or symmetrically weak less than 4	4
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	39

Abdominal muscles. High thoracic curves

Abdominals grade 4-5, symmetrical	18
Abdominals less than grade 4, symmetrical (-ve Beever)	16
Abdominals asymmetrical, weak towards convexity	2
Abdominals asymmetrical, weak towards concavity	2
No record	1
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	39

Arm muscles—The muscles from the scapula to the trunk—trapezius, serratus anterior, rhomboids, pectoralis major and latissimus dorsi—have been charted. There is evidence to be referred to later which suggests that the scapulo-humeral muscles play no part.

In many cases the upper limbs have been normal and an attempt was first made to group the arm-trunk muscles as a unit.

High thoracic curves

Arm-trunk muscles. Normal both sides	15
Arm-trunk muscles. Weak on the convexity	10
Arm-trunk muscles. Weak on the concavity	6
Arm-trunk muscles. Symmetrically weak	8
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	39

To judge the effect of individual muscles is more difficult because it is uncommon to find an isolated asymmetrical paralysis. The latissimus dorsi was particularly referred to by Colonna and Vom Saal, and grading was therefore recorded in detail.

	Cases
Latissimus dorsi grade 4 to normal, bilateral	20
Latissimus dorsi grade 4 weak on the convexity	7
Latissimus dorsi grade 4 weak on the concavity	6
Equally weak or no record	6
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An attempt was made with the other muscles to record the findings where the discrepancy on the two sides was notable between pairs of muscles irrespective of the other arm-trunk muscles.

	Patients
Trapezius weak on convexity	5
Trapezius weak on concavity	4
Serratus anterior weak on convexity	5
Serratus anterior weak on concavity	3
Pectoralis major weak on convexity	5
Pectoralis major weak on concavity	4
Rhomboids weak on convexity	8
Rhomboids weak on concavity	4

This slight predominance of weak arm muscles on the convexity is not statistically significant. It would, from the nature of the disease, be expected that in one-sided paralysis the anterior horn cells whose axons go to the arm and the intercostals of the same side might be involved more often and more seriously than on opposite sides.

If it is true that the arm-trunk muscles have no effect upon the spine, and scoliosis is seen only in the presence of intercostal paralysis, and arm paralysis when present is coincidental, then it should be possible to find a group of patients with arm paralyses but normal intercostal muscles and see what has happened to their spines.

There have fortunately been available the records of 280 patients who suffered from limb paralysis who have been followed over the last four to five years in a study of muscle recovery carried out by my colleague, W. J. Sharrard. From these records, and additional cases of my own, there is a group of thirty-eight patients who have had unilateral arm-trunk muscle involvement and retained normal power in the intercostals. Many of these patients developed poliomyelitis after injections into the arm. This usually results in severe paralysis of one arm with the trunk muscles unaffected. The follow-up period from the onset of poliomyelitis is in no case less than four years and the average is seven years. Although many of these patients are still not fully grown it is apparent from Table I and Table III that well over half of them should have developed thoracic scoliosis within the past seven years, or even four years. In fact, none has scoliosis. One patient had his spinal accessory nerve divided at the age of three years. Despite a total paralysis of one trapezius he had no scoliosis when seen at the age of twenty-six years. No scoliosis has been seen among a large number of these patients who have had paralysis of the upper limb distal to the arm-trunk muscles if the intercostals were normal.

Case 1—A boy of twelve years developed poliomyelitis at the age of four years, and scoliosis was noticed six months later. At the age of eleven years he had a curvature of 81 degrees to the left, extending from the first to the eighth thoracic vertebrae, with slight apical rib collapse (Figs. 5 and 6).

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This boy had an intercostal paralysis: 4 1. In addition he had a weak right deltoid.

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Case 2—A girl aged fourteen years who developed poliomyelitis at the age of seven and scoliosis at eight years. There was paralysis of the right arm which has entirely recovered. After complete

FIG. 5

Case 1—Early high thoracic paralytic scoliosis. Note elevated left trapezius.

FIG. 6

Case 1—The radiograph shows a left high thoracic curve of 81 degrees, extending from T.1-8, with moderate rib collapse.

muscle charting no abnormality was found except in the intercostal muscles where the right side was

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much weaker. The charting was: 0 3. Her vital capacity was 650 cubic centimetres. When she

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first attended she had a curve of 122 degrees with very severe collapse of the first to the tenth ribs on the right side (Figs. 7 and 8). Recent correction in a distraction jacket gave correction to 70 degrees.

FIG. 7

FIG. 8

Case 2—Characteristic high thoracic scoliosis. The radiograph (Fig. 8) shows a right high thoracic curve of 122 degrees, associated with intercostal paralysis and collapse of ribs. The primary curve extended from T.1–10.

THORACIC PARALYTIC SCOLIOSIS

In thoracic paralytic scoliosis the upper limit of the primary curve is at the level of the third thoracic vertebra or lower, but the apex of the primary curve is higher than the eleventh thoracic where the thoraco-lumbar pattern begins. In idiopathic scoliosis this group is the most common and most severe, but the remarkable restriction of severe curves to the thoracic region is not seen in paralytic curves. In this group of sixty-nine patients there were thirty-six females and thirty-three males. An unexpected and unexplained finding is that, as with idiopathic thoracic curves, there is a predominance of curves to the right—fifty-four to the right and only fifteen to the left. Colonna and Vom Saal found the distribution approximately equal. In this group of thoracic curves, though not in the high thoracic or other groups, the muscle paralysis has most often been right-sided. The great majority of these patients have developed thoracic scoliosis within two years of the paralysis. Figure 9 shows the interval between poliomyelitis and the discovery of scoliosis. Thoracic curves varied in site and length; they may extend as low as the fourth lumbar vertebra. The length of the primary curve varied between four to thirteen vertebrae, most being eight to ten vertebrae in length.

Prognosis—Thirty patients had completed spinal growth as indicated by the iliac apophysis. The prognosis of the thoracic group was, in the small series available, distinctly better than the high thoracic. Among the thirty mature curves eight remained mild, ten were severe

and twelve increased to more than 100 degrees (Fig. 10). Among the remaining thirty-nine immature curves seventeen were mild, thirteen severe and nine very severe; several patients had undergone fusion and their expected deterioration had been arrested.

FIG. 9

Thoracic paralytic scoliosis. Interval between poliomyelitis and onset of scoliosis (sixty-two patients).

FIG. 10

Thoracic paralytic scoliosis. Thirty mature curves.

Muscle paralysis in relation to thoracic scoliosis—This group of scolioses has not so clear nor so consistent a relationship as the high thoracic curves. It might be expected that both arm-trunk and abdominal muscles might play their part, and play it differently, depending

on whether the curve starts at the third thoracic level or much lower. It is apparent, though less clear, that the intercostal muscles are, irrespective of level, still the dominant cause of deformity.

Trunk muscles—Six patients with normal or good intercostal muscles had rather small curves—86 degrees, 60 degrees, 50 degrees, 49 degrees, 30 degrees and 23 degrees respectively. All but one of these patients showed no rib collapse, and one showed only slight collapse. The cause of the scoliosis in these patients was not apparent. Two patients had paralysis limited to the intercostal muscles.

Intercostals. Thoracic curves

Intercostals symmetrical 4-5	6
Intercostals symmetrical less than 4	2
Intercostals asymmetrically weak on convexity	41
Intercostals asymmetrically weak on concavity	1
Inadequate or no records	19
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	69

Erector spinae. Thoracic curves

Erector spinae normal 5	35
Erector spinae grade 4	17
Erector spinae less than 4	15
No record	2
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	69

Lateral abdominal flexors. Thoracic curves

Lateral abdominal flexors grade 4 to normal	33
Lateral abdominal flexors symmetrical less than 4	10
Lateral abdominal flexors weak on convexity	15
Lateral abdominal flexors weak on concavity	8
No record	3
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	69

Ten of these with weak lateral flexors on the convexity had primary curves involving lumbar vertebrae.

Anterior abdominal muscles. Thoracic curves

Anterior abdominal muscles 4 to normal, symmetrical	9
Anterior abdominal muscles symmetrical, less than 4	48
Anterior abdominal muscles weak on convexity	8
Anterior abdominal muscles weak on concavity	3
No record	1
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	69

Of the eight patients with weak abdominals on the convexity, seven have primary curves including the first to the fourth lumbar vertebrae.

Arm muscles

Arm-trunk muscles. Thoracic curves

Arm-trunk muscles normal both sides	39
Arm-trunk muscles equally weak	13
Arm-trunk muscles weak on convexity	9
Arm-trunk muscles weak on concavity	7
No record	1
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	69

Latissimus dorsi. Thoracic curves

Latissimus dorsi grade 4 to normal	40
Latissimus dorsi equally weak right and left	6
Latissimus dorsi weak on convexity	13
Latissimus dorsi weak on concavity	5
No record	5

 69

Trapezius weak on convexity	2	Serratus anterior weak on convexity	4
Trapezius weak on concavity	4	Serratus anterior weak on concavity	3
Pectoralis major weak on convexity	5	Rhomboids weak on convexity	4
Pectoralis major weak on concavity	5	Rhomboids weak on concavity	2

A number of these patients wore abduction frames for paralysis of one upper limb. This has been said to be a factor in producing scoliosis. Among the 280 patients previously mentioned there were ninety-seven who wore an abduction frame for more than four months and none of these had developed curvature when last seen.

Case 3—A girl aged eleven years developed poliomyelitis. She now has a curve of 120 degrees (right) extending from the fourth to eleventh thoracic vertebrae. She was not seen until the age of fifteen

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years when surgical fusion was undertaken. All arm muscles are grade 4. Intercostals: 1 3. The

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ribs are collapsed in the mid-zone from about the third to the eighth ribs (Figs. 11 and 12).

Case 4—An Anglo-Indian boy developed poliomyelitis at the age of one year and now at the age of ten years his curve measures 96 degrees. This proved correctable to 29 degrees and fusion was carried

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out. His vital capacity was 600 cubic centimetres. Intercostal charting was: 1 3. The erector

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spinae muscles were normal. The left arm (on the side of concavity) was weaker than the right (Figs. 13 and 14).

The role of the intercostals in thoracic scoliosis—In high thoracic paralytic scoliosis the intercostals seem to be the only muscles consistently paralysed on the convex side of the curve. In thoracic scoliosis they are more commonly paralysed on the convex side than any other muscle, but there are six patients who have normal intercostal muscles and scoliosis. The anterior abdominal muscles and the lateral abdominal flexors appear to play a part, and it is noteworthy that in the cases in which they may be deforming, the curvature is at the low thoracic level and involving the lumbar vertebrae—in fact they resemble thoraco-lumbar curves. The arm and trunk muscles seem to play no part, and it is to be noted that charting of these muscles is very accurate in comparison to the trunk muscles.

The marked asymmetry of the intercostal muscles as measured by chest expansion is often localised to the area of the curve. This could be secondary to chest deformation from the scoliosis rather than from paralysis of the intercostals. However, during the period of observation of these patients several hundred patients with idiopathic scoliosis have been examined by muscle charting, and asymmetric intercostal movement had not been found in scoliosis from this or other causes. Because the ribs are crowded together on the concave side of the curve it would seem that if there was any restriction it should be found on this side.

An important aspect of intercostal paralysis which has seldom before been more than briefly mentioned is the phenomenon of rib descent. On the convex side of the curve, and usually limited to the area of the thoracic curvature, the ribs are strikingly deformed and crowded. The main deformity is a rib droop. Instead of being horizontal they become almost vertical, and sometimes completely so. These vertically lying ribs are crowded together and

FIG. 11

Case 3—Thoracic paralytic scoliosis. Right thoracic curve of 120 degrees.

FIG. 12

Case 3—A curve of 120 degrees between T.4-11. Middle ribs 3-8 are collapsed. Iliac apophyses almost complete.

FIG. 13
Case 4—Before operation.

FIG. 14
Case 4—A typical thoracic curve of 96 degrees between T.5 and L.1. Mid-zone rib collapse. Weak intercostals.

lie one behind the other. Their position is the opposite of that of the ribs in idiopathic scoliosis, in which the ribs on the convex side of the curvature may even spread apart, and it is the ribs on the concave side which crowd together; there may be some change from the horizontal towards the vertical but only comparable to that seen in slighter cases of paralytic rib drooping.

Among the thirty-nine high thoracic curves all showed structural changes in the ribs, and in only three could it be called slight. Among the sixty-nine thoracic curves there were fifty-eight with abnormal rib position. The eleven with normal ribs included the six patients without detectable paralysis of intercostal muscles. One patient, with a left thoraco-lumbar scoliosis, has a right apical rib collapse and no scoliosis. Otherwise rib change without thoracic scoliosis has not been seen in children.

In an attempt to confirm the view that these rib changes were indicative of intercostal paralysis, ten patients were observed by cineradiography. In each of these patients one respiratory cycle was screened and photographed. This strip of film was joined to make a continuous film which can be projected indefinitely from a special projector so that one respiratory cycle can be studied for as long as desired.

In brief, the results of this study of rib movements showed that these vertical ribs ascended through about half the excursion of the rib on the other side. It was often clearly seen that rib movements, which were small in the ribs attached to the vertebrae of the primary curve, were normal or greater than normal in the remaining ribs of the same side. Clinically the rib droop is associated with a razor-edge rotation; and radiographic evidence of rib deformity, or the clinical finding of razor-edge deformity, is most suggestive of paralytic scoliosis. Figures 15 to 18 show these rib changes.

Illustrative Cases

Case 5—This girl, now aged twenty-seven years, had poliomyelitis at the age of nine years and

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developed a high thoracic curve of 121 degrees. Intercostal charting is recorded as: 2 0. Figure 15

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shows the first to the seventh ribs to be dropped. The upper ones are almost vertical.

Case 6—A girl now aged nineteen years developed poliomyelitis at the age of thirteen years. Despite this late onset she developed a severe high thoracic scoliosis of 125 degrees (Fig. 16). The first to the seventh ribs on the convex side of the spinal curve are almost vertical, lying one behind the other.

Case 7—This girl aged eleven years died after atelectasis—a recurrent event since she had been in a respirator for three months at the onset of paralysis eight years before. The two radiographs taken with an interval of three years are seen in Figures 17 and 18. They show characteristic early paralytic rib collapse which later became fully developed.

THORACO-LUMBAR PARALYTIC SCOLIOSIS

This group, intermediate between the well defined thoracic and lumbar curves, is a mixture of the two. The curves themselves are variable, and relating the paralysis to the curvature is on many occasions difficult or impossible. Restriction of the term thoraco-lumbar to those curves in which the eleventh or twelfth thoracic vertebrae form the apex follows the definition accepted in idiopathic thoraco-lumbar scoliosis.

Forty-seven cases have been studied, of which twenty-five were in girls and twenty-two in boys. There were thirty-four curves to the right and thirteen to the left. Although less closely related to muscle paralysis in this area, the large number of right-sided curves is as difficult of explanation as in the thoracic region. The unknown factor by reason of which 80 to 90 per cent of idiopathic thoracic curves are right-sided may well be operating here. The frequent occurrence of scoliosis within two years of the onset of paralysis is demonstrated in Figure 19.

The site of these curves varies considerably and they may involve from six to thirteen vertebrae, usually one or two more than their idiopathic counterparts.

FIG. 15

FIG. 16

Figure 15. Case 5—High thoracic curve of 121 degrees. Collapse of ribs 1-7. There is no chest expansion in the upper two-thirds of the left chest and the ribs are seen to be drooped and crowded. Figure 16. Case 6—Collapse of ribs 1-7.

FIG. 17

FIG. 18

Case 7. Figure 17—Scoliosis of 58 degrees and early rib collapse. Figure 18—Two and a half years later curvature has increased to 118 degrees and the rib collapse now resembles that seen in nearly all cases of high thoracic scoliosis.

Rib collapse, almost always basal, was seen in twenty-five patients; seventeen had none; and in four no record was available. Only eighteen of this group had completed growth. It is a small number from which to obtain significant facts, but the prognosis of these is

FIG. 19

Thoraco-lumbar paralytic scoliosis. Interval between poliomyelitis and onset of scoliosis (forty-seven patients).

represented in Figure 20. The remaining twenty-nine patients, who are still growing, showed twelve mild curves, eleven severe and six very severe; some have been operated upon.

Muscle paralysis in thoraco-lumbar scoliosis—Difficulty is found in explaining some of these in terms of asymmetrical muscle paralysis. In this grouping also we find an important number

FIG. 20

Thoraco-lumbar paralytic scoliosis. Eighteen mature curves.

of curvatures related to a symmetrical weakness of muscles; a "telescopic" spine appears slowly to assume a structural curve from gravity rather than muscle pull. This will be discussed again. The trunk muscles will first be reviewed.

Trunk muscles**Erector spinae. Thoraco-lumbar curves**

Erector spinae symmetrical 4 to normal	20
Erector spinae symmetrical less than 4	26
No record	1
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	47

Lateral abdominal flexors. Thoraco-lumbar curves

Lateral abdominal flexors symmetrical 4 to normal	15
Lateral abdominal flexors weak on convexity	21
Lateral abdominal flexors weak on concavity	2
Lateral abdominal flexors less than grade 4 symmetrical	8
No record	1
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	47

Anterior abdominal muscles. Thoraco-lumbar curves

Anterior abdominal muscles grade 4 to normal symmetrical (-ve Beevor)	6
Anterior abdominal muscles weak on convexity	8
Anterior abdominal muscles weak on concavity	2
Anterior abdominal muscles symmetrically weak	31
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	47

Intercostals. Thoraco-lumbar curves

Intercostals symmetrical 4 to normal	10
Intercostals weak on convexity	11
Intercostals weak on concavity	4
Intercostals symmetrically weak less than 4	8
No record	14
	<hr/>
	47

The arm muscles, gluteus maximus, psoas and leg abductors were checked and were not related. The noteworthy feature in these muscle charts was the frequency with which the lateral abdominal flexors were weak on the convexity. This will be discussed more fully in the lumbar group. The intercostals may play a small part; basal weakness was found on the convexity on a number of occasions. The other aspect of muscle weakness was the frequency of weakness of the erector spinae (twenty-six cases) and of the anterior abdominal muscles (thirty-one cases). This might be found in the presence of symmetrically strong lateral flexors, with marked lateral asymmetry, or all three groups might be equally weak on the right and left sides. In two instances almost no paralysis could be detected and in one other only the anterior abdominals. Although I believe that collapse of the spine from the force of gravity is important in the etiology of thoraco-lumbar scoliosis it should be made clear that the cause of this curvature in terms of precise muscle paralysis is not explained in a number of cases.

A real shortening of one leg of more than one inch occurred on the convexity (where it might be expected) three times, on the concavity five times. Contracture of tensor fasciae latae, said by Irwin (1949) to be a cause of paralytic scoliosis, occurred bilaterally once, on the side of the convexity three times, and on the concavity once. Pelvic obliquity, a feature of paralytic scoliosis in the lumbar region, occurred eleven times, in all but one in association with inequality of the lateral flexors, this inequality being the cause of pelvic obliquity (Mayer 1936).

Illustrative Case

Case 8—Now fourteen years old, this patient had developed poliomyelitis at the age of seven years. One year afterwards curvature was noticed and progressed rapidly. At the age of ten a fascial graft was placed between the left iliac crest and ribs to try to prevent further deformity arising from the totally paralysed lateral flexors and intercostals on the left side. It did not slow deterioration and the curvature increased to 130 degrees and extended over eleven vertebrae from the fifth thoracic to the

third lumbar, the apex being at the eleventh and twelfth thoracic. She had a gross pelvic obliquity

R. L.

2 2

from the inequality of the lateral flexors, right 4, left 0. The intercostal charting was: 1 1. Gross

1 0

muscle imbalance accounted for this curvature, but in addition the abdominals and erector spinae were symmetrically weak and allowed additional collapse (Figs. 21 and 22).

FIG. 21

FIG. 22

Case 8. Figure 21—Thoraco-lumbar scoliosis. Gross inequality of the lateral abdominal flexors together with collapse due to symmetrical weakness of other muscles caused this severe thoraco-lumbar curve. Figure 22—A long 130 degrees thoraco-lumbar curve with rib collapse and marked pelvic obliquity.

LUMBAR PARALYTIC SCOLIOSIS

This group of cases, few in number, provides a clear cut entity with a related muscle paralysis, as noted by Colonna and Vom Saal. There were seventeen cases of lumbar paralytic scoliosis, eleven male and six female. Twelve were right sided, four left. The interval between the paralysis and the onset of curvature is on the average longer than in the other groups. Only twelve patients had completed growth. These numbers are too small to be significant. However, the number of mild cases was two, severe seven and very severe three. It would appear that the prognosis is little better than in other groups—very different from the idiopathic curves of this region.

The top vertebrae of these curves varied between the levels of the sixth thoracic to the first lumbar. The apex, however, was always in the lumbar vertebrae. The length of the curve varied between five and thirteen vertebrae.

The important group of muscles causing lumbar scoliosis appears to be the lateral abdominal flexors—the quadratus lumborum, lateral portion of the anterior abdominal muscles, and in two patients perhaps the latissimus dorsi. In established curves, trick elevation of the pelvis can be produced by the erector spinae but it is never powerful.

Associated with imbalance between the lateral flexors is a pelvic tilt. The strong lateral flexors pull the pelvis up on the side opposite the convexity. Apparent shortening must

accompany this and may be as much as three inches. Early in this pelvic elevation the soft-tissue contracture becomes fixed and the pelvic tilt cannot be altered by manual pull on the leg. In these seventeen patients there was a notable pelvic obliquity in twelve, and imbalance between the lateral flexors in the same twelve. One had no abnormal muscles except his right lateral flexor group which was grade 2. He developed one and a half inches of apparent shortening and an 88-degree curvature to the right (Figs. 23 and 24).

The remaining five patients with normal or symmetrically weak lateral flexors had considerable generalised trunk weakness and are regarded as having "telescopic" spines.

The detailed muscle charting proved to be as follows:

Lumbar paralytic scoliosis			
Erector spinae 4 to normal	.	.	6
Less than 4 symmetrical	.	.	11
			—
			17
Lateral abdominal flexors grade 4 to normal	.	.	3
Symmetrically weak less than 4	.	.	2
Asymmetrically weak on the convexity	.	.	12
Asymmetrically weak on the concavity	.	.	0
			—
			17
Anterior abdominals grade 4 to normal	.	.	3
Symmetrically weak less than 4	.	.	11
Asymmetrically weak on convexity	.	.	2
Asymmetrically weak on concavity	.	.	1
			—
			17

It seems that if the intercostals play any part at all it is only small. Gluteus maximus, psoas and the leg abductors were in no way related. In three patients there was more than one inch of true leg shortening on the convex side, in two on the concave side. Three patients had slight bilateral contractures of the tensor fasciae latae.

It would seem from this series that, except when due to spinal collapse, lumbar paralytic scoliosis (always associated with pelvic obliquity and apparent shortening) is due to asymmetrical weakness of the lateral abdominal flexors. These are laterally placed muscles like the intercostals acting through long levers.

Illustrative Cases

Case 9—A boy aged twelve who developed poliomyelitis at five years of age and scoliosis at seven years. The only persisting paralysis was of the right lateral flexors, grade 2. The left were normal. He developed a lumbar curve from the tenth thoracic to the fourth lumbar vertebra of 88 degrees. There was one and a half inches of apparent shortening of the left leg and pelvic obliquity. His deformity is typical of most lumbar curves from lateral flexor imbalance (Figs. 23 and 24).

Case 10—In contrast, this man aged twenty years has a "collapse" type of lumbar curve. Although he developed poliomyelitis at the age of four years his curve was not noted until he was fifteen years of age. It is very long, involving thirteen vertebrae, and is only of 70 degrees, two typical features of collapse curves. He has symmetrically weak erector spinae and abdomen, but he did have slight asymmetry of the lateral flexors (Figs. 25 and 26).

One-sided absence of gluteus maximus may produce a non-structural curve when sitting, due to a unilaterally wasted buttock; this can be corrected by a block under the buttock. Muscle paralysis in this region of the body has also been investigated in the same large group of 280 patients previously referred to in discussing arm paralysis in relation to thoracic scoliosis. Among the children in this group inequality of the psoas muscles of more than one

FIG. 23

FIG. 24

Case 9. Figure 23—An isolated right lateral abdominal flexor weakness and 88 degrees of lumbar scoliosis. Figure 24—Lumbar curve with gross obliquity of pelvis. The approximation of ribs to pelvis by the stronger lateral flexor is well illustrated.

FIG. 25

FIG. 26

Case 10—Lumbar paralytic scoliosis. Figure 25—Lumbar "collapse" curve. Figure 26—Radiograph showing the long curve. Some pelvic obliquity.

grade occurred twenty-two times but no scoliosis developed. Similarly twenty-one asymmetrically paralysed glutei maximi were noted without curvature. In this same group of paralysed children the lateral flexors were symmetrically paralysed fourteen times and in one instance only was asymmetry present without scoliosis, lateral flexors of grade 3:0 being found in a boy of six without curvature. However, in some of the thoracic scoliotics reviewed there has been abdominal lateral flexor imbalance which has not produced scoliosis in the lumbar region.

Irwin is of the opinion that one tight tensor fasciae latae is a cause of scoliosis. No instance of scoliosis and a tight tensor fasciae latae has been found in which there was not also adequate lateral flexor paralysis to explain the deformity. Amongst forty-seven thoraco-lumbar curves unilateral tightness of the tensor fasciae latae was found three times on the convexity, once on the concavity. In seventeen lumbar curves no instance of unilateral tightness of tensor fasciae latae was found. Twelve cases of unilateral contracture have been observed among the 280 patients; none developed scoliosis. Apart from the mild non-structural compensatory scoliosis from the hip abductor contracture it is believed that this deformity is not significant. Shortness of a leg has in this series borne no relationship to the curvature. In a special clinic for leg inequality no structural scoliosis has been seen, nor have unequal legs been found to be relevant in a series of several hundred idiopathic scoliotics.

COMBINED THORACIC AND LUMBAR PARALYTIC SCOLIOSIS

The last and smallest group (fifteen cases) need not be discussed in detail. However, it does exist and it is important that it should be recognised because fusion of only one primary curve may be followed by an increase in the second primary curve with disastrous result. The apophyses of the ilium had completed their growth in only six cases. In four, both primary curves remained mild; the other two were respectively 116 degrees : 79 degrees and 150 degrees : 104 degrees. The relationship of these curves to the muscle paralysis was often puzzling. However, in eight instances the intercostal muscles were weak on the side of convexity of the upper primary curve, and never on the concave side of the deformity. Three patients had normal intercostals and two were not recorded. In five patients weakness of the lateral flexors occurred on the convexity of the lower curve, in four on the concavity but two of these had both curves confined to thoracic vertebrae. All other relevant muscles were charted and found not to be significantly related to the curvature.

Case 11—A girl aged ten developed poliomyelitis and this was immediately followed by scoliosis. She now has a right thoracic curve of 78 degrees from the third to tenth thoracic vertebrae and a left lower primary of 70 degrees from the eleventh thoracic to fourth lumbar. There was slight weakness of the right intercostals but no other evident related weakness (Figs. 27 and 28).

In idiopathic scoliosis the double primary pattern is common and uniform in character. In paralytic scoliosis it is uncommon and variable and believed to be due to a fortuitous paralysis of deforming muscles on opposite sides in the upper and lower curves respectively.

TELESCOPIC SPINE

In paralytic scoliosis there is often a considerable difference in the erect and supine curve measurements. This is the natural result of weakness of the trunk muscles and difficulty in overcoming the effect of gravity. The curve in a collapsing spine will usually diminish when the patient lies down, or more remarkably, in suspension. The importance of this factor in thoraco-lumbar and lumbar curves has already been stressed; it should always be remembered.

There were, however, in this group, eight patients who had gross but symmetrical anterior, lateral abdominal and erector spinae paralysis rarely above grade 3. These patients did not develop severe structural lateral curves although they did tend to produce correctable and

FIG. 27

Case 11—Combined thoracic and lumbar paralytic scoliosis. The right thoracic rotation is evident in both photographs but lumbar rotation is difficult to see except in the erect view.

FIG. 28

FIG. 29

Figure 28. Case 11—Two primary curves, 78 degrees and 70 degrees. Figure 29. Case 12—Antero-posterior deformities. Erector spinae graded 0/0/3 0/0/2. Abdomen 2. Lateral flexors 3.

non-structural thoraco-lumbar curves on sitting or standing. Many of these patients have flail spines and require long fusions for stabilisation.

In addition to the lateral curves developed, paralysis of the erector spinae and anterior abdominal muscles produces quite marked antero-posterior curves. Thoracic kyphosis with lumbar lordosis is seen in all eight patients (Fig. 29). It is believed that paralysis of the mid-line muscles produces antero-posterior and not lateral curves as its major effect, a view earlier expressed by Steindler.

An unusual type of paralysis has been seen on three occasions, a rather strictly segmental lumbar paralysis of erector spinae and the abdominals of the same segments. Gravity produces a small lumbar kyphosis in the erect position (Fig. 30).

PROGNOSIS AND THE AGE OF ONSET

In idiopathic scoliosis the age at which curvature begins has an important bearing on prognosis, but less so than the site of the primary curve.

In paralytic scoliosis it has been demonstrated that the site of the primary curve is less important in prognosis than is the degree of muscle imbalance. Just as in the limbs, so in the trunk, muscle imbalance arising early in childhood causes a more severe deformity than does paralysis towards the end of growth. A total of ninety-two patients were found to have completed growth without alteration of their natural development by operation. In Figure 31 it can be seen

FIG. 30

Localised erector spinae paralysis with kyphosis.

FIG. 31

Relationship of final curvature to age at onset of poliomyelitis.

that children who developed poliomyelitis before five years of age developed more serious deformities than did those in the two groups, six to ten years and eleven to fifteen years. In the youngest group the most common final curve is more than 100 degrees whereas in the oldest group the most common final curvature is less than 70 degrees.

POLIOMYELITIS IN ADULTS

Structural lateral deformity has not been seen in any girl who developed poliomyelitis after the age of fourteen or boy after fifteen. Thirty-four adults followed up over several years who had sufficient and appropriate paralysis for the development of scoliosis failed to deform.

THE RELATIONSHIP OF POLIOMYELITIS TO IDIOPATHIC SCOLIOSIS

It has often been said that idiopathic scoliosis is due to unrecognised poliomyelitis. There are many reasons why this cannot be, despite recent electromyographic evidence (Riddle and Roaf 1955).

Routine complete muscle charting of idiopathic scoliosis has not revealed isolated paralysis of limb muscles. The suggestion that several hundred children have been afflicted with isolated paralysis of their rotatory muscles leaving all other muscles unaffected and without a history of acute illness is too unlikely to be maintained. Moreover, in idiopathic scoliosis the curves are shorter and less mobile on the average, and do not present a high thoracic pattern. Finally, 90 per cent of patients with idiopathic scoliosis, appearing after ten years of age, are females.

SUMMARY

1. The prognosis of paralytic scoliosis has been studied by defining curve patterns and establishing the natural development as seen in fully grown patients who have not had surgical correction.
2. The prognosis, unlike that in idiopathic scoliosis, is related to the age of onset of the curvature and the degree of muscle imbalance rather than the site of the primary curve.
3. Paralysis of limb muscles is shown to be unrelated to the development of scoliosis. The intercostal muscles and the lateral abdominal flexors produce scoliosis when weaker on the convex side of the curve. Gravity and the other trunk muscles certainly play a part in the development of lumbar curves but their importance is difficult to assess.

REFERENCES

- BOPPE, M., and QUENEAU, P. (1949): A propos des scolioses poliomyélitiques. *Revue d'Orthopédie*, **35**, 12.
- CARLES, F. (1909): Sur quelques cas de scoliose. *Revue d'Orthopédie*, **10**, 43.
- CLEVELAND, M. (1951): Paralytic Disorders. *In* Surgical Treatment of the Motor-skeletal System. Edited by F. W. Bancroft and H. C. Marble. Vol. 1, Chapter 7. Philadelphia, London, Montreal: J. B. Lippincott Company.
- COBB, J. R. (1952): Correction of Scoliosis. Papers and Discussions Presented at the Second International Poliomyelitis Conference, p. 250. Philadelphia, London, Montreal: J. B. Lippincott Company.
- COLONNA, P. C., and VOM SAAL, F. (1941): A Study of Paralytic Scoliosis Based on Five Hundred Cases of Poliomyelitis. *Journal of Bone and Joint Surgery*, **23**, 335.
- CORNELL, W. Burgess (1905): Infantile Paralysis of the Abdominal Muscles, with Report of a Case. *Johns Hopkins Hospital Bulletin*, **16**, 11.
- DESFOSSÉS, P. (1909): A propos de la scoliose consécutive à la paralysie infantile. *Presse Médicale*, **17**, 184.
- EATON, G. O. (1941): Results of Abdominal Stabilization. *Southern Medical Journal*, **34**, 443.
- FARKAS, A. (1943): Paralytic Scoliosis. *Journal of Bone and Joint Surgery*, **25**, 581.
- FARKAS, A. (1945): The Treatment of Paralytic Scoliosis. *Medical Press and Circular*, **213**, 342.
- HOWORTH, H. Beckett (1952): A Textbook of Orthopedics. Philadelphia and London: W. B. Saunders Company.
- IRWIN, C. E. (1949): The Iliotibial Band. *Journal of Bone and Joint Surgery*, **31-A**, 141.
- JONES, Sir R., and LOVETT, R. W. (1929): Orthopaedic Surgery. Second edition, p. 463. London: Oxford University Press.
- KLEINBERG, S. (1951): Scoliosis. London: Baillière, Tindall & Cox.
- LACKUM, W. H. von (1951): Surgical Treatment of Scoliosis. *In* Surgical Treatment of the Motor-skeletal System. Edited by F. W. Bancroft and H. C. Marble. Vol. 1, Chapter 6. Philadelphia, London, Montreal: J. B. Lippincott Company.
- LOWMAN, C. L. (1932): The Relation of the Abdominal Muscles to Paralytic Scoliosis. *Journal of Bone and Joint Surgery*, **14**, 763.

- McMURRAY, T. P. (1949): *A Practice of Orthopaedic Surgery*. Third edition, p. 228. London: Edward Arnold & Co.
- MAYER, L. (1936): Further Studies of Fixed Paralytic Pelvic Obliquity. *Journal of Bone and Joint Surgery*, **18**, 87.
- MAYER, L., and GREENBERG, B. B. (1942): Measurements of the Strength of Trunk Muscles. *Journal of Bone and Joint Surgery*, **24**, 842.
- MESSNER (1892): Über Asymmetrie (halbseitige Atrophie) des Thorax und Kontrakturen der Wirbelsäule nach Kinderlähmung. *Centralblatt für Chirurgie*, **19**, 897.
- MITTELSTAEDT, W. (1920): Über Bauchmuskellähmungen bei Poliomyelitis. *Zeitschrift für die gesamte Neurologie und Psychiatrie*, **58**, 1.
- RIDDLE, H. F. V., and ROAF, R. (1955): Muscle Imbalance in the Causation of Scoliosis. *Lancet*, **i**, 1,245.
- SKINHØJ, E. (1949): Some Problems of Acute Anterior Poliomyelitis and its Sequelae. Copenhagen: Einar Munksgaard.
- SOFIELD (1949): In Discussion. Papers and Discussions Presented at the First International Poliomyelitis Conference, p. 225. Philadelphia, London, Montreal: J. B. Lippincott Company.
- STEINDLER, A. (1929): *Diseases and Deformities of the Spine and Thorax*. London: Henry Kimpton.
- WALLACE, G. T., and WEST, W. J. (1947): Fascial Repair for Poliomyelitic Paralysis of the Abdominal Wall in Adults. *Journal of Bone and Joint Surgery*, **29**, 1,031.
- WERNER, A. Y., ZUMETA, G. R., NEWMAN, R. W., and HINES, H. M. (1951): Comparison of Vital Capacity in Normal and Poliomyelitic Subjects. *Journal of Bone and Joint Surgery*, **33-A**, 628.
- WILLIAMSON, G. A., MOE, J. H., and BASOM, W. C. (1942): Results of the Lowman Operation for Paralysis of the Abdominal Muscles. *Minnesota Medicine*, **25**, 117.