EVOLUTION OF SPINAL FUSION

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DISCUSSION OF THE EVOLUTION of spinal fusion must necessarily begin with the names of Russell Hibbs and Fred Albee, as these two men were the first to develop methods of spinal arthrodesis and to further the general use of these procedures by the orthopedic surgeon. Hibbs, in 1910, devised a method of using fragments from the spinous processes and laminae as a means of obtaining bony ankylosis, whereas Albee used a graft of free bone from the tibia of the patient. Hibbs had observed, in studying the pathology of tuberculosis of the spine after treatment with plaster encasements or braces, that in many cases a spontaneous bony ankylosis of the lateral articulations and occasionally of the laminae and spinous processes had occurred. Sometimes even the vertebral bodies were found to be fused together. He observed, also, that this natural ankylosis was usually incomplete, sometimes including the joint on only one side, and usually lagging behind the tuberculosis as it advanced up and down the spinal column. He found that it took many years for the ankylosis to occur, and that it rarely resulted in complete healing of the disease. Hibbs reasoned that if the ankylosis could be produced operatively, safely, and more quickly than would occur by the natural process, that the complete splinting effect afforded thereby might result in more rapid and more certain healing of the disease. He stated: "One of the reasons why the disease is so persistent in its destructive effect on the bodies of the vertebrae is because of the motion which takes place between them, and while the various methods of treatment limit the motion, none absolutely prevents it. In the light of our present knowledge and experience the greatest need in the treatment of this disease, both from the standpoint of shortening its duration and preventing its deformity, is the perfection of a method which will absolutely immobilize the spine throughout the diseased area and make development of deformity impossible. The writer has done an operation for stiffening the knee joint[1] . . . ", which "led to the conception if the periosteum of the spinous processes was carefully removed, and the processes were divided at their bases, and placed longitudinally in the interspinous space touching with either end the base from which the processes were removed and then the periosteum brought back and sutured, a similar condition would be produced."[2] On January 9, 1911, after preliminary work on the cadaver, with the assistance and encouragement of George Huntington, of the Department of Anatomy of Columbia University, Hibbs performed the first spinal fusion on a living subject, a boy with tuberculosis of the spine. The

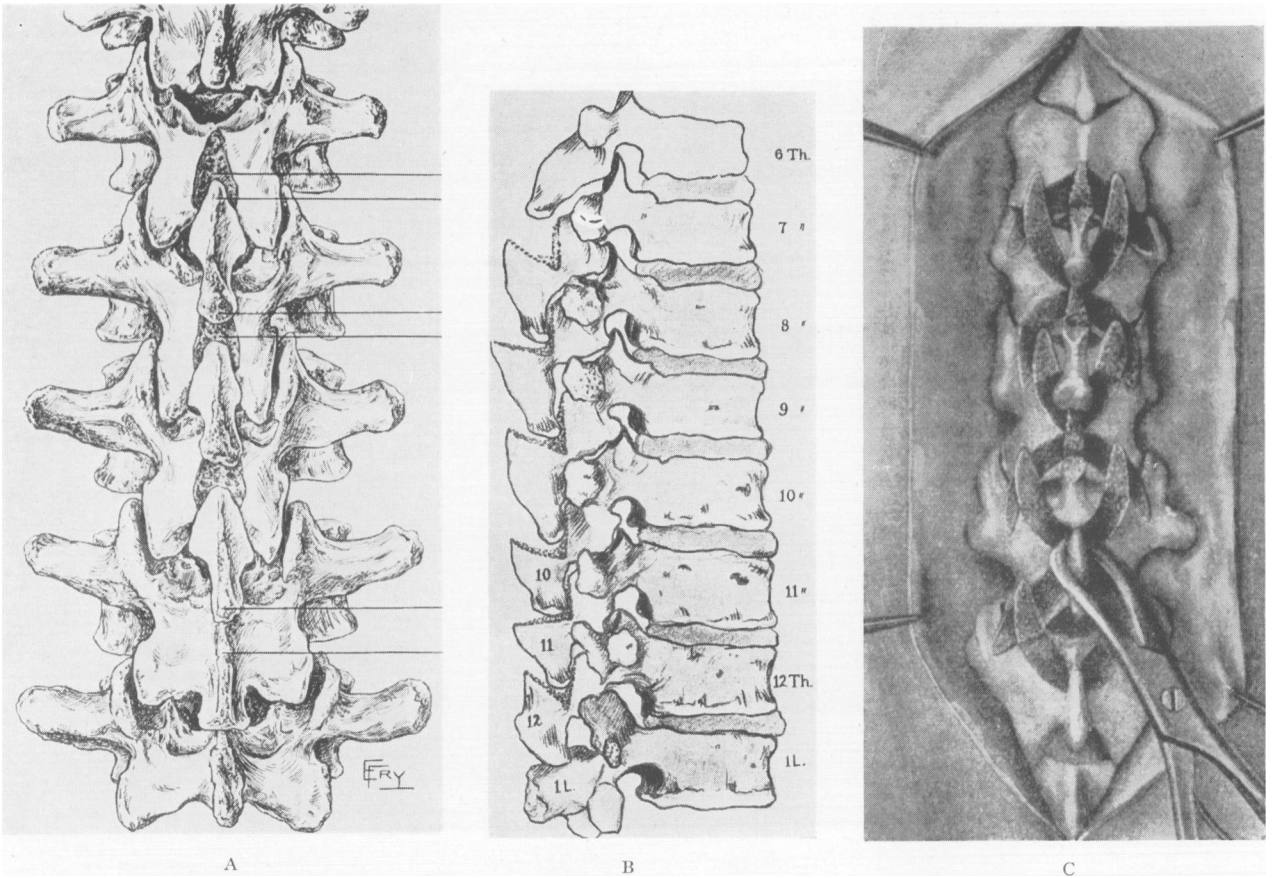

FIG. 1.—A. Original illustration used by R. A. Hibbs[2] in describing the first fusion operation (May, 1911). B. Illustration used in description of the operation including the use of chips from the laminae[4, 4a] (May, 1912). C. Hibb's[7a] illustration showing extended use of the fragments from the laminae and curettage of the lateral articulations (January, 1924).

Volume 117
Number 2

patient recovered from the operation without complication, bony ankylosis occurred, and, over a period of months, the tuberculous lesion healed. Hibbs reported the operation on this and two other patients on May 27, 1911—"An Operation for Progressive Spinal Deformities[2]" (Fig. 1A). In this report he added: ". . . In the very young, however, I think it will be necessary to graft bone from the leg. This is a perfectly practical procedure." Further, ". . . No case of lateral curvature has yet been done, but I propose to do exactly the same operation, and if it is not sufficient, to do an arthrodesis between the lateral processes.[2] We see from these quotations how complete was Hibbs' conception of the principles involved.

In September of the same year, Albee[3] reported three cases which he had treated in June and July by the use of a tibial graft implanted in the spinous processes. He stated: ". . . Previous to the herein reported cases, five patients were operated on and three or four spinous processes were split . . . and the tip of the lower half of the superior vertebra was then brought into approximation with the tip of the superior half of the next lower vertebra after green-stick fractures of each, and fastened with heavy kangaroo tendon. Chips of bone from the spinous processes were then placed in between so as to insure further bone union between these vertebrae. This union has been satisfactory so far as can be ascertained, but on account of its uncertainty and the large amount of cartilage in the vertebrae of small children, with its slowness of union and early lack of support, it has seemed best to devise a procedure which would be possibly more reliable and also give support from the beginning. These requirements can be fulfilled in no other way except by a strong bone graft. The different sources from which to secure a strong bone graft for an internal splint, which would give immediate support to the spine, were considered, and the crest of the tibia was selected as by far the most desirable and accessible."

Hibbs[4, 4a] operated upon 43 cases with tuberculosis of the spine in the first year. These cases were reported in April, 1912 (Fig. 1B), and at this time Hibbs mentioned an extension of the operative procedure, stating that: "The space between the laminae is bridged by elevating a small piece of bone from the edge of the lamina, and placing it transversely across, its free end in contact with the lamina next below, with the gap between the spinous processes filled by their transposition. This makes me doubt the necessity for suturing the periosteum as I think bone becomes continuous and that a fusion takes place of the vertebrae operated upon." He emphasized here the complete subperiosteal dissection of the spinous processes and laminae as far laterally as the bases of the transverse processes. He further mentions suturing the periosteum of the spinous processes together on each side to close the gap produced by the interspinous ligament but questions the necessity for this step. Farrell[5] reported many additional cases in January, 1915.

In June, 1917, Hibbs[6] reported eight cases in which the spinal fusion was used in scoliosis for the prevention of increasing deformity and improvement in the stability of the spine. The first of these operations was performed in 1914. We note here the application of the suggestion made by Hibbs, in 1911, regarding the treatment of the lateral articulations: "The first thing to be done is to curet the lateral articulations which lie at the base of the transverse processes and are easily reached in children and in most adults."

In June, 1918, Hibbs[7] reported 210 cases of spinal tuberculosis treated by the fusion operation, at which time he emphasized the use of special gauze packings to prevent bleeding and secure a clear field. Also, he pointed out that in the lumbar spine it was often desirable to split the spinous processes, turning portions of it upward and other portions downward, interdigitating these fragments. Fifty-nine fusion operations for scoliosis were reported[7a] in January, 1924, and the further development of the operation described (Fig. 1C). Thus we have the picture of the development of the fusion to include not only the spinous processes, but the laminae and lateral articulations, resulting in a solid mass of thick bone extending completely across the posterior surface of the spinal column.

This early period should not be dismissed without mention of several other attempts at internal fixation of the spine. Hadra,[8] in 1891, had wired together the spinous processes in treating fracture. Lange,[9] in 1902, had begun to use steel rods sutured in the angles between the spinous processes and the laminae, and subsequently he used celluloid cylinders in a similar manner. Reporting his early work at the meeting of the American Orthopedic Association in 1910, he stated: "We must work for two things in our treatment of these cases; first, we must put our braces under the skin, and second, we must shorten the time for recovery for our patients." DeQuervain and Hoessly,[10] in December, 1911, independently of a knowledge of Albee's work, reported the use of the spine of the scapula as a free graft into the split spinous processes. At the same time they reported an interesting series of experiments on dogs. Gallie,[11] in 1915, attempted arthrodesis by use of prepared beef bone grafts.

Despite the several technics described, this early period was marked not so much by study of the technic of spinal fusion, as by discussion as to whether spinal fusion was justified at all. As the operation was usually undertaken upon children, the possibility of interference with growth of the spine had to be considered as well as that of production of deformity by fusing only the posterior elements of the spine. Some orthopedists feared that fusion would stop the growth entirely, while others said that the vertebral bodies would continue to grow, while the fused posterior portion of the spine would remain stationary. The latter course would have been a desirable outcome in cases of tuberculosis as it would have caused the correction of the kyphosis, but unfortunately this did not occur. It was found, over a period of years, that growth of the spine continued at the

normal rate after fusion, and that the trunk-leg ratio remained the same in these patients as in normal individuals, allowing for the effect of the kyphos. No one knew whether the spines of very young children could be fused. This doubt was probably due to failure to realize that the spinous processes and laminae are ossified, even in the infant, although the lateral articulations and tips of the spinous processes are largely cartilaginous. The young spines did fuse, however, and a successful fusion was accomplished on one infant at the age of eleven months, probably the youngest ever attempted. Fusions were undertaken also for patients past the age of 60, again, with success.

The presence of tuberculosis in and around the laminae and articular processes presented another problem. The bone chips often failed to unite in the diseased area, and at times were even extruded, and sinuses developed, while the disease continued to advance. Furthermore, many of the patients of that day, long sufferers, with marked deformities, had developed amyloid disease, chronic sinuses, spastic paralysis or complications which produced an unfavorable general or local situation.

Many orthopedists feared that the traumatism of operation would stir up the disease and result in its spread as miliary tuberculosis or tuberculous meningitis. It was found, however, that the incidence of these complications was far less during the months following operation than it had been in the patients treated without operation. The operative mortality in the first 20 years of the operation was only 1.4 per cent, whereas 15 per cent of the patients died of pre-existing tuberculosis elsewhere in the body.

MODIFICATIONS

The second period in the evolution of spinal fusion may be characterized as one of modification. Perhaps the low mortality in cases described by Hibbs led to the impression that the operation was so simple that it could be learned through reading its description, or merely seeing it performed once. Lack of familiarity with the operation or lack of skill in its performance resulted in a high percentage of failure in the hands of some orthopedists, as a result of which the operation itself was in some quarters unqualifiedly condemned. Many of those who did not condemn or cease to employ the operation, sought to modify it for the sake of simplicity and reduction of the operative risk in their hands. The portion of the operation which seemed to give the most difficulty was the approach to and treatment of the lateral articulations. Forbes,[12] in 1920, omitting the inclusion of the lateral articulations in the fusion, split each spinous process and lamina into several fragments instead of two or three as Hibbs had been doing. Radulesco,[13] in 1921, reported a modification of the Albee procedure, in which half a rib, with periosteum attached, was used instead of a tibial graft. Brown,[14] and also Kleinberg,[15] in 1922, reported the use of beef bone grafts along with a partial fusion operation. Thomas,[16] in November, 1923, reported

the use of an osteoperiosteal graft and what he described as "wafer chips." Several operations extended the procedure beyond the posterior elements of the spine. Led by MacClennan,[17] who resected a portion of the vetrebral body for scoliosis, in 1922, and Royle,[18] who removed a hemivertebra in 1928, Ito[19] inserted bone grafts into slots in the vertebral bodies and reported a number of cases in 1934. Schede,[20] in 1925, used a graft as a prop between the ilium and transverse processes and props have even been used between the ilium and the ribs.

Most of these modifications were unnecessary, and some added an unjustifiable risk to the operation. The significant thing is that the spine was being fused. It matters not so much how a particular chip is laid or from whence a particular fragment of bone comes, but as to whether fusion is obtained, how quickly, and how strong.

APPLICATION TO OTHER CONDITIONS

A further development marked this second period—the application of the fusion to other conditions than tuberculosis and scoliosis. Hibbs,[21] in 1922, reported the use of the fusion in 22 cases of "fracture-dislocation of the spine," the cases dating from 1916. The first one of the series was an unrecognized instance of spondylolisthesis, and represents the first application of the procedure to this anomaly. At least eight additional cases in this group had spondylolisthesis, but there were also cases of compression fracture of the spine. The operation was also applied to the other lumbosacral anomalies,[22] such as the acute lumbosacral angle, posterior displacement of the fifth lumbar vertebra, transitional lumbosacral joints, and deformities of the lateral articulations. The first lumbosacral fusion for a mechanical condition was performed in October, 1914. It has also been employed in cases of round back, hemivertebra,[23] with or without partial resection, osteomyelitis,[24] occasionally in localized osteo-arthritis of traumatic origin, and, rarely, in other conditions. We have been doing the fusion in conjunction with removal of the ruptured nucleus pulposus since November, 1937.

OPERATIVE TECHNIC

The principle of the Hibbs operation has remained the same, but there have been several useful minor modifications. Hibbs devised a rasp which was driven into the lateral articulation for the purpose of scraping out the articular cartilage. It was found that even the rasp and curet usually did not effectively bare the articular surfaces. At the present time the articular cartilage with a little of the underlying cortical bone is removed with a straight osteotome or one especially angled for the purpose. Usually, the spinous process is removed and cut into long thin fragments which are eventually laid across the interlaminal spaces. If there is not sufficient bone at the site, as in some cases of spondylolisthesis or spina bifida, additional bone may be secured by removing neighboring spinous processes, or from the

region of the posterior superior iliac spine. The present procedure is, in general, as follows: A midline incision is made through the skin and subcutaneous tissue, and skin towels are applied with Michel clips. The deep fascia and supraspinous ligament are incised, and, with a Kermison elevator, the ligament is stripped from the tip of the spinous processes. The interspinous ligaments are incised longitudinally. The periosteum is carefully

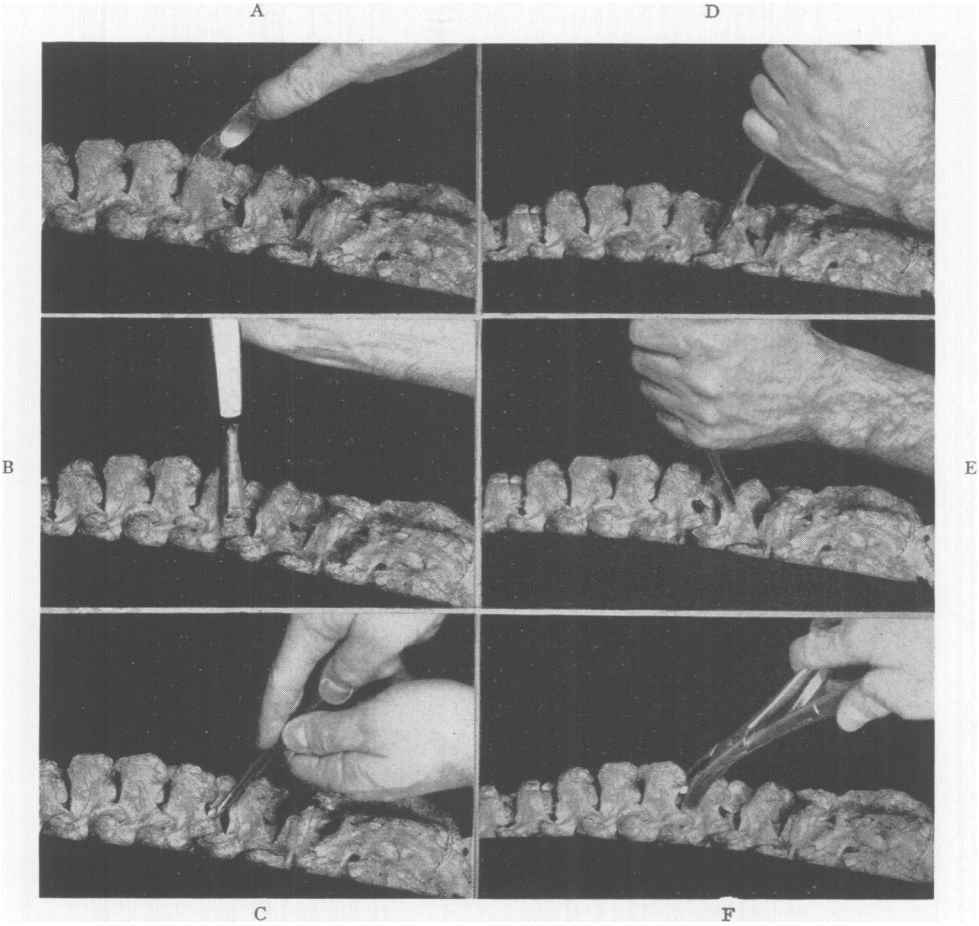

FIG. 2.—Technic of Spinal Fusion: A. Elevation of periosteum from spinous processes and laminae with Kermison and sharp, curved elevators. B. Completion of subperiosteal dissection and stripping of posterior capsules with "chisel" elevator. C. Dissection of interspinous ligament and posterior two-thirds of ligamentum flavum with curets, baring margins of the laminae and spinous processes. D. Excision of articular cartilage and subjacent cortical bone with straight or angled osteotome. E. Gouging of chips, into articular gap, subjacent fossae, and interlaminal spaces. The operation is completed by turning or placing the fragments from the spinous processes longitudinally from lamina to lamina. F. Removal of spinous processes. (This step is done in various ways and at various periods by different operators.)

stripped with sharp periosteal elevators from the spinous processes and laminae, far enough laterally to completely expose the lateral articulations (Fig. 2, A to F). This exposure is sharply limited, however, as there are usually blood vessels just beyond the lateral articulations which may be troublesome if opened. Further dissection may often be simplified by removal of

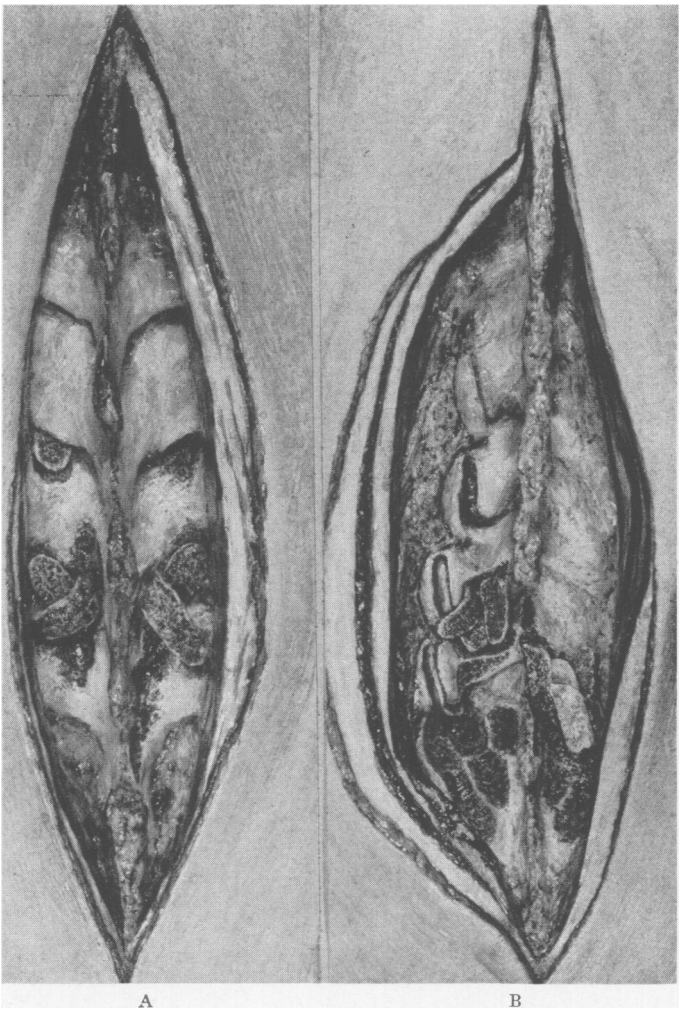

FIG. 3.—Specimens showing successive stages of the spinal fusion operation. A. Thoracic Spine: Subperiosteal dissection of spinous processes and laminae; excision of interspinous ligaments and ligamentum flavum; excision of posterior articular capsules; excision of articular cartilage; insertion of bare chips in articular gap; chips turned across interlaminal spaces from laminae and spinous processes. B. Lumbar Spine: The same, showing also the spinous processes cut into several fragments and placed across the lumbosacral joint, on the right.

the spinous processes at this stage. An assistant can be detailed to cut them into proper fragments or they may be split longitudinally before their removal. Next, the ligamentum flavum is largely removed, leaving only a thin anterior layer. This may be done very simply with a sharp curet by cutting its attachment to the superior margin of the distal lamina, then cutting it from the inferior margin of the proximal lamina, which overhangs it, and peeling it away from its most anterior layer. It is quite important to carefully remove all the ligament from the little fossa subjacent to each lateral articulation. The articulation is then denuded of cartilage and cortical bone with

osteotome and curet, with particular care to include all of the articular surface in the cup-shaped or oblique articulations, but to avoid penetration of the instruments or fragments of cartilage into the intervertebral foramen. A small fragment of bone is turned up with a gouge and jammed into the gap between the articular processes, and the whole fossa is bared of cortical bone by gouging up successive small chips which are locked together to form a small compact mass filling the fossa. Some operators prefer simply to insert a fragment of bone from the spinous process into the interarticular gap and do not thoroughly denude the articular cartilage or the fossa, which we consider the most crucial point in the fusion. Next, chips are cut with the gouge from the laminae and turned across the interlaminal spaces, interdigitating, and left attached at their bases as much as possible. Then the longer fragments from the spinous processes are laid longitudinally across the interlaminal space (Fig. 3 A and B). If the chips are simply dumped in like jackstraws, to lie in any direction and any location, the chances of pseudarthrosis are greatly increased. The careful placement of these chips is of greatest importance.

Finally, closure is made carefully and in anatomic layers. The periosteum and muscles are snugly sutured over the chips so as to obliterate any potential dead space, which might permit a large hematoma and allow displacement of the chips. The interspinous and supraspinous ligaments are then sutured, and finally the fascia and subcutaneous tissue, and the skin.

POSTOPERATIVE CARE

The postoperative care depends somewhat upon the condition for which the operation is undertaken. The general care of the patient is important, including adequate calcium and phosphorus, vitamins, and transfusions or iron if anemia is present. The chief feature of postoperative care is proper immobilization of the spine by bed rest and a brace or plaster jacket until the fusion has become sufficiently strong to support the weight of the trunk, and ordinary body movements. The patient is placed on a bed with a firm mattress and fracture board. Those with scoliosis are operated upon through a fenestrated plaster jacket, and the jacket is then reinforced. Other cases have a Taylor brace applied. Turning by the nurse is permitted, on the side, prone or supine, usually on a four-hour schedule. The patient is turned in such a way as to move the trunk *en masse*. Patients with a simple lumbosacral anomaly or compression fracture are kept in bed for about six weeks and wear the brace for a total of four months. Patients with spondylolisthesis, scoliosis, or tuberculosis remain in bed about 12 weeks. Those with scoliosis wear a jacket for an additional three to six months, while the others wear a brace for a somewhat shorter period. These patients return to their regular activities within three months to one year following operation, depending upon the original condition, the progress of the fusion, and the character of the patient's activities.

COMPLICATIONS

It is to be expected that there will be an occasional failure of fusion, just as there are failures of union in the treatment of fractures, in osteotomies, and in bone grafts. However, these failures should be minimal and it should be realized and admitted that if they represent any appreciable percentage of the total number of cases, they must be ascribed to the technic of the operation and the postoperative immobilization. For example, during the five years 1931 to 1935, inclusive, more than 600 spinal fusions were done for all causes at the New York Orthopaedic Hospital. These operations were performed by the House Staff, Fellows, and Attending Surgeons. One or more psuedo-arthroses occurred in 14 per cent of the cases, nearly all of which were subsequently repaired. The largest number of failures, 18 per cent, was found in the group of spondylolistheses, while the lumbosacral fusions failed in only eight per cent, and in the fracture cases—none. It has been repeatedly demonstrated by clinical examination and roentgenograms, by subsequent operations, and occasionally by necropsy, that fusion can be accomplished in a large percentage of cases. It is futile, at the present time, to ascribe failures to the patient's "refusal to grow bone," or to the character of the operation. The operative mortality in more than 3,000 fusions at the New York Orthopaedic Hospital during the period 1911 through 1937 has been 0.6 per cent, whereas there has been no death from the operation since March, 1935. Thus, it is seen that the operation need not carry an appreciable risk to the life of the patient.

INDICATIONS

The indications for the operation may be summarized as follows, assuming a surgeon capable of properly performing the operation and an institution suitable for the care of the patient:

1. Tuberculosis: The treatment of choice at all ages, unless complete spontaneous natural fusion can be demonstrated, or the general condition of the patient or complications preclude the operation.

2. Scoliosis: In children with rapidly progressive deformity, or deformity with decompensation which can be corrected sufficiently to warrant fixation; in adults, occasionally for relief of pain.

3. Spondylolisthesis: All cases in the lower lumbar region unless contraindicated by age or the general condition of the patient.

4. Other lumbosacral anomalies: Pain of long duration, of moderate or great intensity, frankly due to the anomaly and unrelieved by other treatment.

5. Rupture of nucleus pulposus: Many of these joints are unstable primarily, and should be fused upon removal of the nucleus, preferably without laminectomy.

6. Compression fracture of the spine and some dislocations: As a means of maintaining reduction, hastening convalescence, and preventing pain.

7. With laminectomy: When indicated with a coincident orthopedic condition, or an extensive procedure.

8. Special indications in certain other conditions.

CONCLUSIONS

The effects of the operation should be clearly understood. A fusion may hasten and assure healing of tuberculosis and perhaps sometimes other infections, by completely immobilizing the diseased section of the spine. Progressive deformity due to tuberculosis, scoliosis, and spondylolisthesis may be prevented. The establishment of fusion for this purpose in cases of round back or hemivertebrae is open to question. In scoliosis and fracture, fusion may be the best or only means of maintaining correction of deformity. We do not attempt, and advise against, attempting to correct the deformity in tuberculosis. Fusion may be used for the relief of pain in the lumbosacral anomalies as well as all of the conditions just named. In many cases it may not only aid in the cure of the disease, the arrest or correction of deformity, and the relief of pain, but may be the quickest and most economical method of relief, in this way offering a financial advantage to both patient, hospital, and community. Thus, we see that spinal fusion has evolved during the past 30 years from a "radical" procedure in the treatment of tuberculosis, to a well established operation employed for a number of abnormalities of the spine. It is not a panacea, but in properly selected cases, and in skilled hands, fusion offers little risk and the possibility of great benefit to a large number of patients.

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