SPONDYLOLISTHESIS

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by

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AMONG THE NUMEROUS conditions which give rise to low back pain, spondylolisthesis is of special interest because of major problems which it presents in respect to aetiology, diagnosis and treatment.

It is not a common disease. Furthermore, its recognition is hampered by the fact that of those individuals who possess the vertebral defect which is the essential pathological lesion, only a fraction present themselves with symptoms and signs which lead to a diagnosis. The opportunity to accumulate clinical experience, therefore, is limited. With the notable exception of Friberg's monograph (1939) and Meyerding's paper (1941), most of the references in the literature deal with small numbers of cases. There is still much to be learned about the condition.

Pathological Anatomy

Most cases of spondylolisthesis, though not all, are the result of a bilateral defect in the structure of a vertebra, usually the fifth lumbar. The defect is situated at the narrow portion of the neural arch known as the isthmus. It lies immediately below the superior articular facets and at the superolateral corners of the laminae. The defect is an interruption in the normal bony continuity of the neural arch filled in with fibrous tissue. In dried specimens the fibrous bond disappears during preparation and the vertebra separates into two portions, (1) a posterior fragment consisting of the laminae, spinous process and inferior facets, and (2) an anterior fragment consisting of the body, pedicles, transverse processes and superior articular facets (Fig. 1). This defect is visible in lateral radiographs of the involved vertebra (Fig. 2).

While the defect in the neural arch is commonly bilateral, occasionally it is limited to one side. In such cases diagnosis may be difficult since the deformity is slight and the defect is not easily revealed by radiography, unless oblique views are taken (Fig. 3).

Occasionally the defect of the neural arch is present in more than one vertebra in which case the fourth and fifth lumbar usually are the vertebrae involved (Fig. 4).

When a single vertebra is involved it is the fifth lumbar in the great majority of cases. Occasionally it may be the fourth lumbar vertebra. In this series of one hundred cases, the incidence was: fifth lumbar, 92 cases; fourth lumbar, 8 cases.

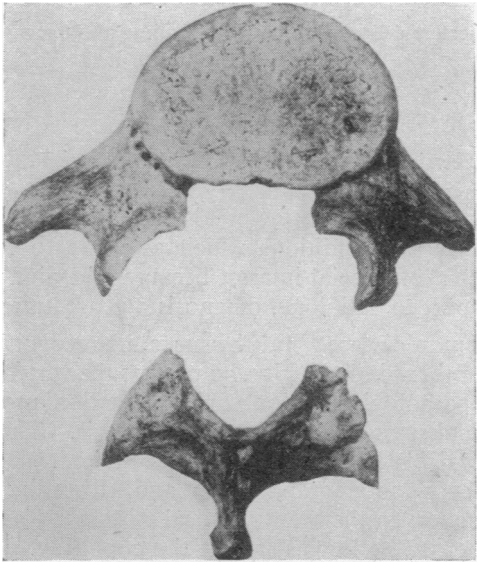

Fig. 1. The defect which is characteristic of spondylolisthesis (fifth lumbar vertebra). Interruption of the neural arch on either side at the isthmus. The anterior fragment consists of body, pedicles, transverse processes, and superior facets; the posterior fragment of laminae, spinous process and inferior facets.

The presence of the characteristic defect in the neural arch renders the fifth lumbar vertebra unstable in relation to the sacrum. Normally the inferior articular facets of the fifth lumbar vertebra are hooked over the superior articular facets of the sacrum in such a manner as to anchor it firmly to the sacrum. If its bony structure is intact and its inferior facets locked over those at the top of the sacrum, the fifth lumbar vertebra cannot shift upon the sacrum. When the defect of spondylolysis exists, it constitutes a weak link between the body of the fifth lumbar vertebra and its inferior articular facets. The fifth lumbar vertebra is then held in place only by the intervertebral disc, the longitudinal ligaments and the fibrous bond which fills the defect at the pars interarticularis. Of these attachments the last is the most critical. It may prove sufficiently strong to resist the stresses incidental to movement and the support of body weight. In that case the patient lives his life without symptoms, without deformity and without consciousness of his defect. On the other hand, the fibrous bond may slowly stretch under the stresses which normally play upon it, or it may be disrupted by a single injury or by repeated injuries. Once the syndesmosis is stretched or disrupted, the body of the fifth lumbar vertebra no longer is anchored securely to the sacrum. Movement and superimposed weight separate it from its inferior articular facets and push it downward and forward across the sloping upper surface of the sacrum.

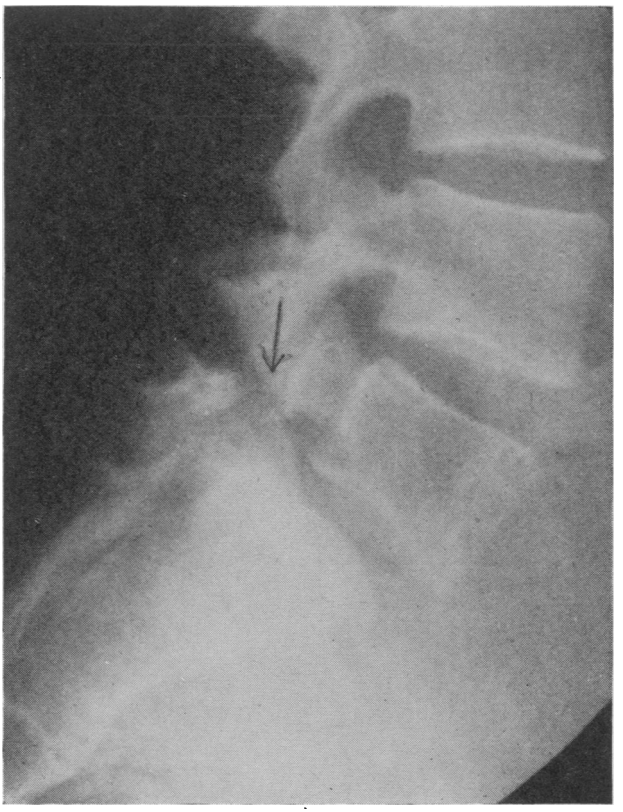

Fig. 2. Lateral radiographs of spondylolisthesis of the fifth lumbar vertebra with small amount of slip. The arrow points to the defect in the neural arch.

As the involved vertebral body slides forward, it carries with it the whole of the spinal column above, without disturbing the relationship between the vertebrae. The posterior fragment of the involved vertebra is left behind anchored to the superior facets of the sacrum below. An ever-widening gap develops between the two portions of the involved vertebra as the body slips forward. The alignment of the tips of the spinous processes is interrupted by a sharp jog, the posterior projecting spine being that of the involved vertebra. The amount of forward slip varies considerably. It may be so great that the body of the fifth lumbar falls off the top of the sacrum completely and comes to occupy a position on the anterior face of it.

We must therefore distinguish between two groups of cases : (1) spondylolysis or prespondylolisthesis, in which the characteristic defect exists in the bony neural arch but is unaccompanied by any forward

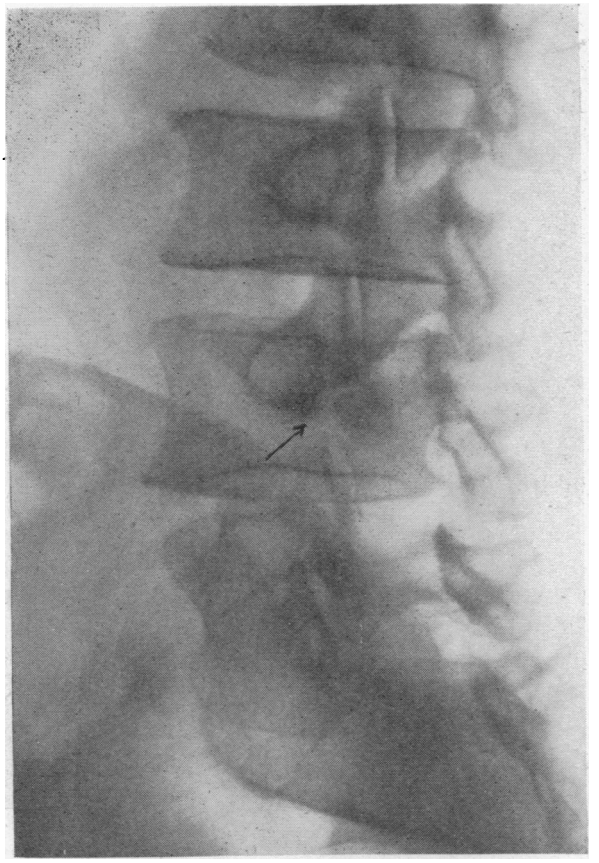

Fig. 3. Oblique radiograph; a projection which is useful to depict the defect in the neural arch when there is no displacement. Arrow points to the defective isthmus.

displacement of the body of the involved vertebra (Fig. 2) ; and (2) spondylolisthesis—those cases in which the defect is accompanied by forward slip of the body of greater or less extent (Fig. 5).

Spondylolysis may exist without symptoms. Such cases must account for the great discrepancy between the incidence of the lesion in anatomical museums and the number of cases recognised clinically. Spondylolisthesis almost invariably causes symptoms, and these are the more severe the greater the amount of slip.

There is another and entirely different mechanism which occasionally results in spondylolisthesis. In such cases there is a deficiency in size or an imperfection in shape of the inferior articular facets of the fifth

Fig. 4. Double lesion of spondylolisthesis involving the fourth and the fifth lumbar vertebrae.

lumbar vertebra. This renders insecure their grasp of the superior articular facets of the sacrum. There comes a time when the defective articulation is dragged apart; the inferior facets of the fifth lumbar vertebra are pulled over or through the superior facets of the sacrum. This in fact is a dislocation. Once the facet articulations are unlocked the entire vertebra is adrift and slips forward under the stress of the superimposed body weight just as does the body of the vertebra with the more common defect at the isthmus of the neural arch. While this mechanism does result in forward slipping of the body of the fifth lumbar vertebra upon the sacrum, and hence may be termed spondylolisthesis in the strict derivational use of the term, it is a rare occurrence (2 per cent. in this series). The usual cause of spondylolisthesis is the bilateral defect in the neural arch at the isthmus.

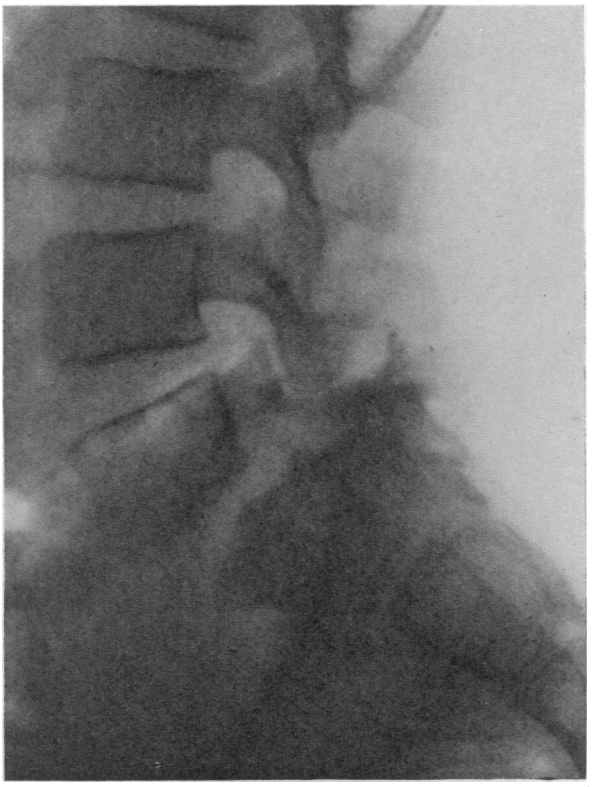

Fig. 5. Spondylolisthesis with moderate forward slip. (See also Fig. 27.)

Frequency of Occurrence of the Defect which Permits Spondylolisthesis to Develop

Since the studies of Willis (1931), it has been recognised that the defective neural arch (spondylolysis) occurs with surprising frequency in the skeletal material in anatomical museums. His figures were 79 cases amongst 1,520 skeletons (5 per cent.). Professor J. C. B. Grant, who has been kind enough to interest himself in this problem on my behalf, has confirmed the findings of Willis from the material in the Department of Anatomy of the University of Toronto. The essential defect, therefore, is common. Its incidence is much higher than is the clinical recognition of the syndrome. This suggests that not all cases of spondylolysis give rise to symptoms of such severity as to necessitate treatment. There is much clinical evidence to substantiate this. In certain cases the lesion is discovered accidentally in patients who have no symptoms. Other patients are so little inconvenienced that they put

up with their backache, do not seek medical advice and hence are not radiographed. It is known also that many cases of spondylolisthesis are without pain until a specific injury precipitates symptoms, yet the defect must have been present before the injury. The recent war provided many opportunities to study spondylolisthesis. A soldier's life is sufficiently strenuous to reveal the weak parts of the framework of his body and since perfect fitness is essential in a soldier, even minor complaints were submitted to adequate investigation. Under these circumstances an unusual number of cases of spondylolisthesis were uncovered. In civil life the true nature of many of these would not have been recognised. Either the patient puts up with his backache, or his doctor may fail to reach an accurate diagnosis from lack of a good radiograph.

Relation of Trauma to Spondylolisthesis

There is much lack of knowledge regarding the manner in which the defect in the neural arch arises. Generally it is assumed that the defect is congenital, the result of an aberration in the ossification of the vertebra. But our knowledge of the ossification of a vertebra does not justify the assumption that it could result from failure of fusion of normal centres of ossification. Normally the vertebrae ossify from three primary centres of ossification, one for the body and one for each half of the neural arch (Fig. 6). At birth these are still separate and their points of contact are (*a*) the junctions of the base of each pedicle with the body; (*b*) the spinous process, where failure of fusion of the two centres for the neural arch gives rise to the familiar spina bifida. The pars interarticularis at this stage is not the narrowest part of the neural arch (isthmus). It is a substantial bar between the superior and inferior articular facets.

The work of Batts (1939) suggests that the lesion is not congenital. He examined the spines of 200 stillborn children and failed to find a single instance of spondylolysis or spondylolisthesis, or any abnormal centres of ossification. If this is a correct observation it must be concluded that the lesion develops after birth, for a corresponding number of adult spines would have shown at least ten cases of defect. The lesion occasionally is recognised in early life. I am indebted to Sir Thomas Fairbank and his associates for calling my attention to spondylolisthesis in a girl aged 4 years, and for permission to publish her radiograph (Fig. 7). Occasionally also spondylolisthesis occurs in parent and child; there is one such pair in this series. If this is not evidence of a congenital origin, it suggests a familial weakness which permits the defect to occur.

Some evidence has been advanced to suggest that the defect may occur as the result of injury at birth, or early in life (Hitchcock, 1940). It is assumed that severe hyperextension of the spine during infancy, such as might occur during a breech delivery, can cause the inferior articular facets of the fourth lumbar vertebra to impinge upon the pars

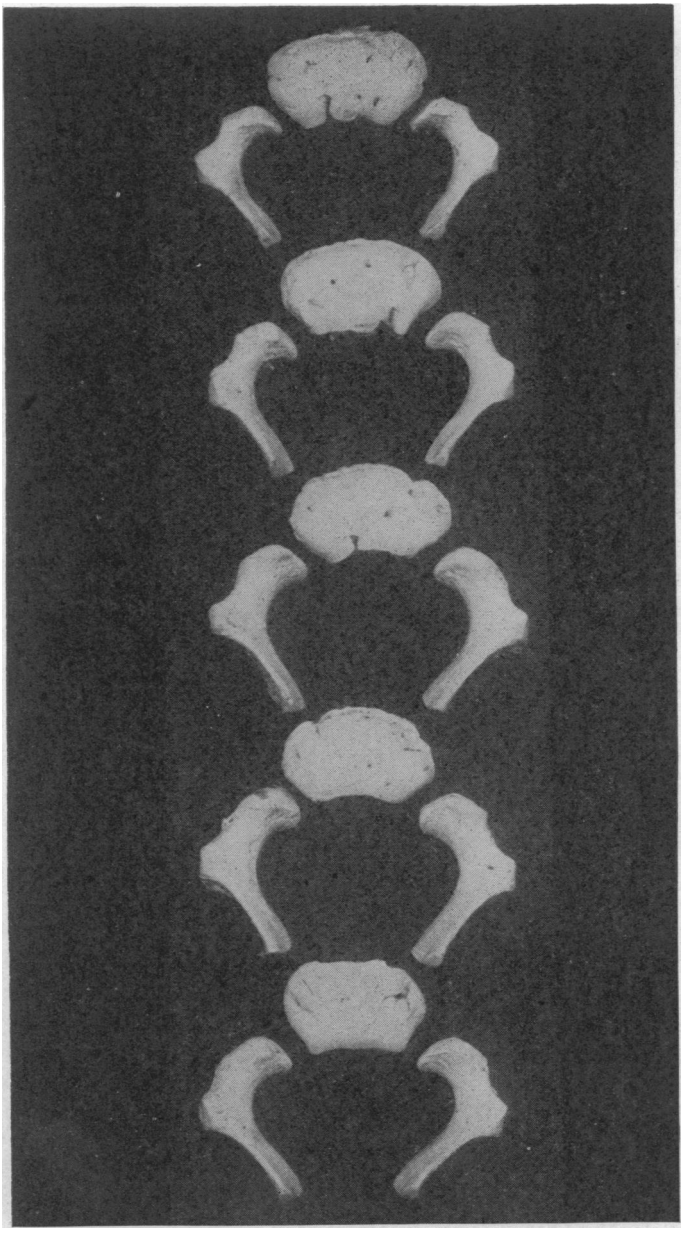

Fig. 6. Lumbar vertebrae of a new-born child. Each vertebra consists of three bony units developed from the three primary centres of ossification and not yet fused with each other. The three units are body, and right and left halves of neural arch.

Fig. 7. Spondylolisthesis (L5 on S1) in a four-year-old girl. The earliest example of the lesion in the experience of the author and for this he is indebted to Sir Thomas Fairbanks. Note, however, Kleinberg's case (1934) in a child 17 months old.

interarticularis of the fifth with sufficient force to disrupt the neural arch at this point. It has been difficult to substantiate or to disprove this hypothesis.

It must be admitted that we know little of the conditions which give rise to the defect in the neural arch at the isthmus which is the essential lesion of spondylolisthesis. Much further study upon this aspect of the problem is needed with the prospect that entirely new concepts will develop from it.

However uncertain the part that trauma plays in *the causation of the primary defect* in the neural arch, it seems definite that often it is the final factor which *determines the onset of symptoms.* Many patients with spondylolysis have no disability of the back until subjected to a single specific injury, often one in which the spine is hyperextended or one in which strong force is exerted vertically downwards upon the spine. From history and clinical observations it seems an inescapable fact that the symptoms, the deformity and the disablement of spondylolisthesis can be initiated by injury.

The frequency with which symptoms are initiated in association with a hyperextension injury may be of important significance. The relationship of the inferior facets of the fourth lumbar vertebra to the isthmus of the fifth lumbar vertebra is such as to suggest that hyperextension may force these facets downwards into the isthmus and crack it open as by a wedge (Fig. 8). If this occurred in an intact vertebra, it would be a fracture. But the defect does not behave as does a fracture; it never, for instance, shows any evidence of healing. Rather than fracture, it seems more likely that the effect of the hyperextension injury is to disrupt a neural arch which already has the characteristic defect of the bony ring (spondylolysis). Up to the moment of injury, the fibrous bond has been sufficiently strong to resist ordinary stresses. Once it has been forced apart by hyperextension or by any other force, it is weak, unstable and can no longer withstand normal stresses.

The relationship of injury to the onset of symptoms is indicated by the following table and case histories.

SPONDYLOLISTHESIS

RELATIONSHIP OF ONSET OF SYMPTOMS TO INJURY

Onset with Hyperextension	Onset with other Injury	Onset without Injury
16	39	45

D. E., female, age 33, an expert diver and swimmer, while high diving entered the water with legs too far over, her back being strongly hyperextended. There was instant pain in the back which persisted and steadily increased. Eighteen months later examination revealed spondylolisthesis of the fifth lumbar vertebra on the sacrum with one-half inch displacement. She had never had any pain or back disability prior to her diving injury.

J. B. F., male, age 44, had no difficulty with his back until he was thrown from a railroad hand car. He landed across the rails on his back, hyperextending it. There was severe pain and disablement which has persisted. Prior to his injury he had worked as a labourer in the bridge and building gang of the Canadian National Railway without any difficulty with his back. He has not been able to work since. Six months after the accident radiographs showed spondylolisthesis with moderate slip.

Fig. 8. Lateral view of lumbar spine showing the relationship of the tip of the inferior facet of the fourth lumbar vertebra to the pars interarticularis of the fifth lumbar vertebra which suggests that on hyperextension of the lumbar spine it can be driven downwards as a wedge to disrupt the isthmus.

S. P., male, age 17, diving into a swimming tank, came up against the bottom of the tank with outstretched hands. The jolt caused pain in his back. Radiographs showed spondylolisthesis with moderate slip. There had been some minor back discomfort prior to this but it had not prevented him from being a leading hockey and football player for his school. Radiographs taken three years previously were interpreted as normal though review suggests that a defect may be present (Fig. 9).

Summarising the little we know of the aetiology of spondylolisthesis we may state that the basic cause probably always is a defect in the bony neural arch at the isthmus. We have no certain knowledge of how

Fig. 9 (*a*) and (*b*). Progression of the degree of displacement in spondylolisthesis. (*a*) Lateral radiographs of 18-year-old youth at the time the condition was first recognised following a diving injury. (*b*) Lateral radiograph of the same patient three years prior to (*a*) when the patient first had mild back symptoms on effort.

this arises ; possible mechanisms are defective ossification of the vertebra, failure of fusion of abnormal centres of ossification, trauma at birth or early in life. Disturbances of ossification seem a more probable primary cause than injury, even though such abnormal ossification does not fit into our present knowledge. The fibrous tissue bond which bridges the primary bony defect in the vertebra may be sufficiently firm to function as though the bony arch were complete ; there are no symptoms, or at most only minimal symptoms throughout life. In other cases the fibrous bond at the defect may give way slowly under the stress of daily use. Symptoms develop insidiously and slowly increase as the deformity increases. Finally there is a group in which trauma plays an important secondary role. The fibrous bond remains intact until disrupted by a single injury, in which case the sudden onset of symptoms and their rapid progression is coincident with the injury.

Clinical manifestations of Spondylolisthesis

The clinical manifestations of spondylolisthesis group themselves under two headings ; pain and deformity. Both are dependent upon

the instability and the displacement of the involved vertebra and their degree is roughly proportionate to the amount of slip which has occurred ; the greater the slip, the greater the number and severity of signs and symptoms.

Pain is the symptom which most commonly attracts attention to spondylolisthesis. It appears in two forms.

The instability of the fifth lumbar vertebra and the stresses due to its abnormal mobility give rise to pain experienced in the midline, low in the lumbar region. It does not radiate. It has the qualities of all pain of spinal origin : it is accentuated by weight bearing, lifting and movement and is relieved by recumbency and rest. Its intensity roughly parallels the degree of displacement. Generally it is less severe than one might expect from the pathological change revealed by the radiograph. In many cases this backache commences insidiously early in life and increases in severity very slowly, requiring years to reach an intensity sufficiently severe to require treatment. In other cases the backache is initiated by injury.

It should be emphasised again that not every case of spondylolysis or even every case of spondylolisthesis suffers from low back pain. The known incidence of spondylolysis (5 per cent.) as demonstrated by examination of material in anatomical museums is greatly in excess of the number of cases who come for treatment. There must be many cases who have no pain, and perhaps many others whose pain is no more than a nuisance. As yet we lack accurate information on the symptomless group. Probably it can only be obtained by mass X-ray survey. Occasionally, however, chance reveals a case which demonstrates that spondylolisthesis may be painless even though there is considerable deformity. An example is a Canadian sergeant who, during physical examination upon discharge from the army because of wounds received in action, was found to have the characteristic deformity and radiographic findings of spondylolisthesis, with forward displacement of the body of the fifth lumbar vertebra one-quarter of its diameter. He had been five years in the Army in an infantry regiment, had undergone prolonged and strenuous training, had taken part in the Italian campaign till he was wounded at Rimini, but had never had to report sick because of his back. He had no symptoms referable to it and was unaware that there was anything wrong with it.

The second type of pain is due to pressure upon the roots of the sacral plexus and is less common than the backache. It occurred 36 times amongst the 100 cases which form the basis of this essay. It may develop from two different causes. Under the stresses developed by the slipping vertebra, the disc between the fifth lumbar and first sacral vertebrae is crushed and its nucleus or annulus is extruded backwards in such a manner as to press upon a nerve root. This, commonly, will be the first sacral nerve. Such root pressure manifests itself by the well-known syndrome of the extruded nucleus ; pain radiating down the leg to the

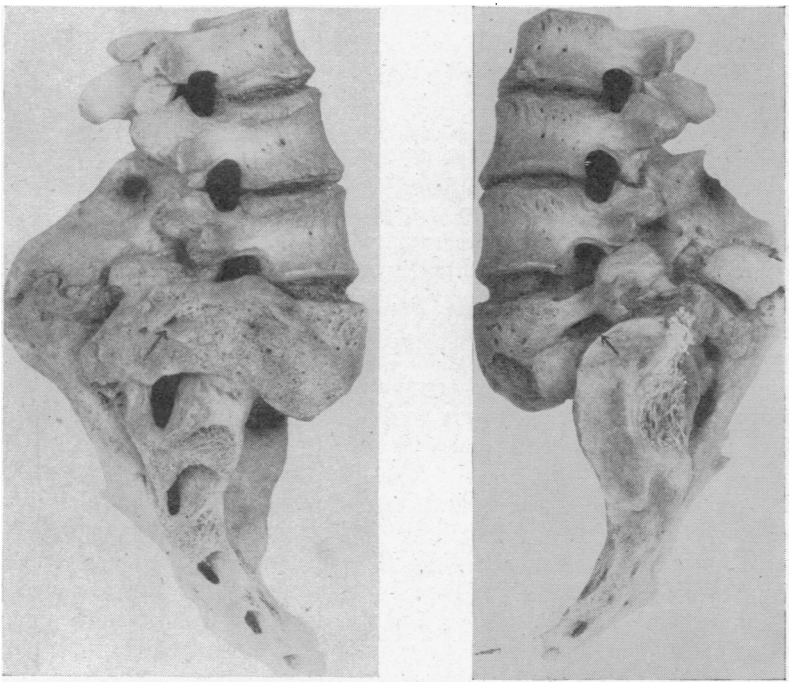

Fig. 10. Postmortem specimen of spondylolisthesis with severe slip six years following bone graft (L3 to S3) to show particularly the great diminution in size of the intervertebral foramen between L5 and S1, especially on the right side, through which the fifth lumbar root emerges. In this patient there was complete paralysis of the peronei on the right side and sensory loss in the area of the fifth lumbar root.

outer margin of the foot in the sensory area of the first sacral root (sciatica), diminished or absent ankle jerk, atrophy of the calf and occasionally demonstrable weakness of the muscles of the calf. Sciatic pain is the conspicuous symptom and it is almost always unilateral. The second mechanism which produces root pressure is distortion and narrowing of the intervertebral foramina between the fifth lumbar and first sacral vertebrae by the altered relationships caused by the forward slip of the former (Fig. 10). By this the fifth lumbar nerve is commonly involved, and usually on both sides. The compression of the root is severe, and bilateral sciatica in the sensory area of the fifth lumbar root is marked. A conspicuous feature is the severe involvement of the muscles supplied by this root, amounting often to complete paralysis of the peronei and dorsiflexors of the foot and toes, with foot drop and varus.

Backache is the common symptom. If the patient's spondylolysis or spondylolisthesis gives rise to any symptoms, backache is the first and most frequent manifestation. In a certain proportion of cases, root pressure pain may accompany the backache. Backache is due to

instability of the involved vertebra ; root pressure pain is due to involvement of the roots of the sacral plexus by extrusion of the nucleus of the disc or to narrowing of the intervertebral foramina between the fifth lumbar and the first sacral vertebrae.

In rare instances evidences appear of pressure involvement of the cauda equina (numbness in the saddle area, disturbances of bladder and of genital function). This occurs when there is great displacement of the body of the fifth lumbar vertebra with extreme angulation and tortuosity of the spinal canal with resulting pressure upon the cauda equina. It is remarkable that this does not occur more frequently. The probable explanation is that the nature of the defect and the resulting slip causes a great widening of the spinal canal which counteracts partly the distortion due to the angulation.

Deformity.—The deformity of spondylolisthesis is very characteristic. It is based upon the forward slip of the involved vertebra. When this becomes great, there are added a variety of compensating mechanisms, all of which must be recognised.

As the body of the involved vertebra slips forward, it carries with it all of the vertebrae above but leaves behind its own laminae, spinous process and the inferior articular facets. Consequently there is a step-like jog in the alignment of the tips of the spines, the involved spinous process being farther back than those above it (Fig. 11). When present and visible, this abrupt step in the spines is very distinctive. Sometimes it is obscured by obesity and can only be felt. It sometimes is evident when the patient stands but disappears when he lies prone. This is due to accentuation of the forward slip on weight bearing. Occasionally it is not evident even when the amount of slip is appreciable.

In sliding forward the involved vertebra carries with it the trunk above. This displaces forward the centre of gravity. To compensate for this, the lumbar spine is hyperextended and the upper part of the trunk thrown farther backwards.

In an attempt to re-align the weight of the body and to support it more adequately, the pelvis is rotated about a transverse axis so that the sacrum becomes more vertical. The clearest evidence of this is seen in the elevation of the anterosuperior spine in relation to the posterosuperior spine. Normally below the level of the posterosuperior spine, in spondylolisthesis, the anterosuperior spine rises to the same level or even higher (Fig. 12).

This rotation of the pelvis may become so great in cases of extreme slip as to cause a peculiar change in posture. The hip joint rotates with the tilt of the pelvis till the thigh, even in the extreme of full extension at the hip joint, fails to place itself vertically beneath the trunk. In consequence, if the man stands with his trunk erect, his hips remain slightly flexed and then his knees must be flexed also. If he stands with his legs straight, his trunk must be tilted forward from the hips (Fig. 13).

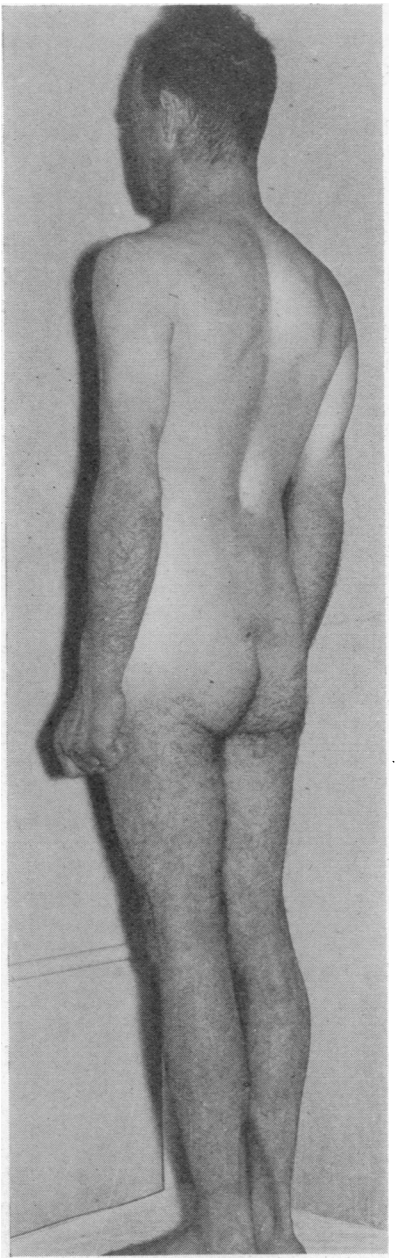

Fig. 11. Photograph of patient with spondylolisthesis to show a characteristic element of the deformity; the step-like jog in the alignment of the tips of the spinous processes. The prominent spine is that of the involved (L5) vertebra.

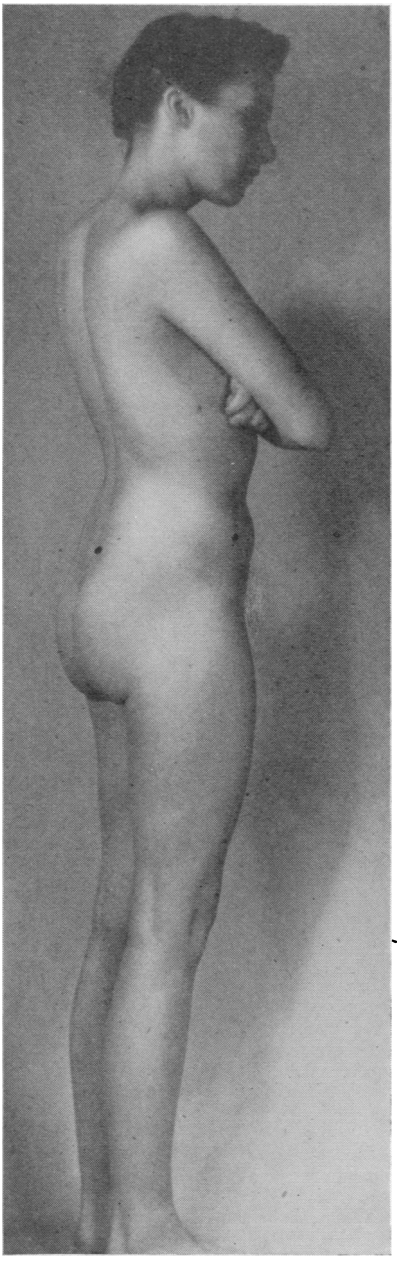

Fig. 12. Spondylolisthesis with moderate slip to illustrate the characteristic rotation of the pelvis about a transverse axis passing through the hip joints with resulting elevation of the anterior superior spine of the ilium until it is higher than the posterior superior spine. Both anterior superior spine and posterior superior spine have been marked with Indian ink.

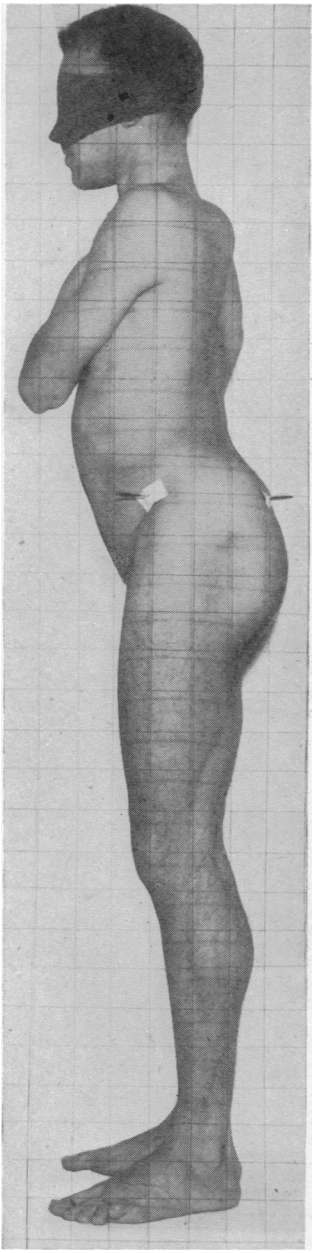

Fig. 13. Spondylolisthesis with severe slip. In such cases the rotation of the pelvis is greater than the full range of extension of the hip joint. Consequently, if the limbs are fully extended at the knees, the trunk is tilted forward. The trunk can only be poised vertically over the feet by allowing the thighs to tilt forward and compensating for this by flexion at the knees. Pointers mark the anterior superior and posterior superior spines. In this patient the deformity persists after successful fusion because the bone graft was performed in the position of displacement.

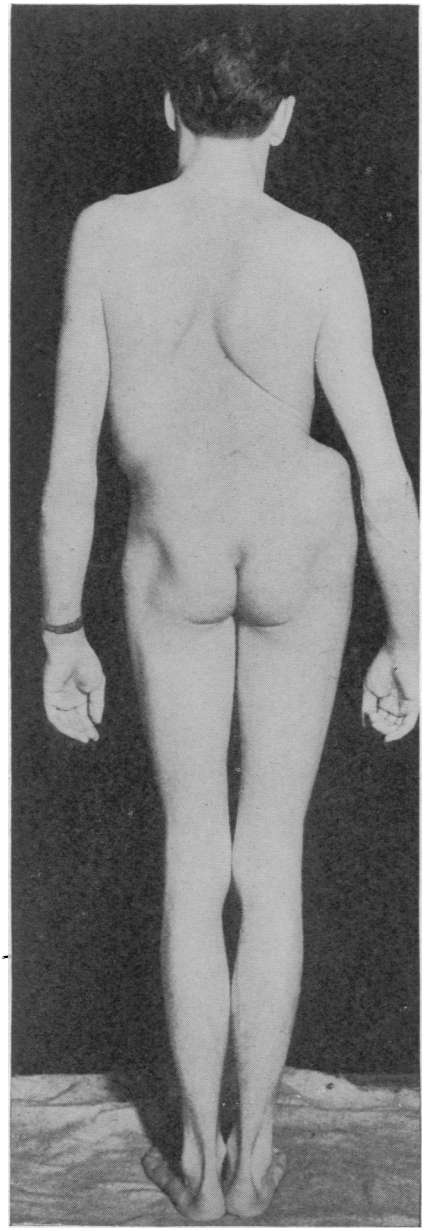

Fig. 14. Severe deformity in a case of spondylolisthesis with great displacement. (See Fig. 25.)

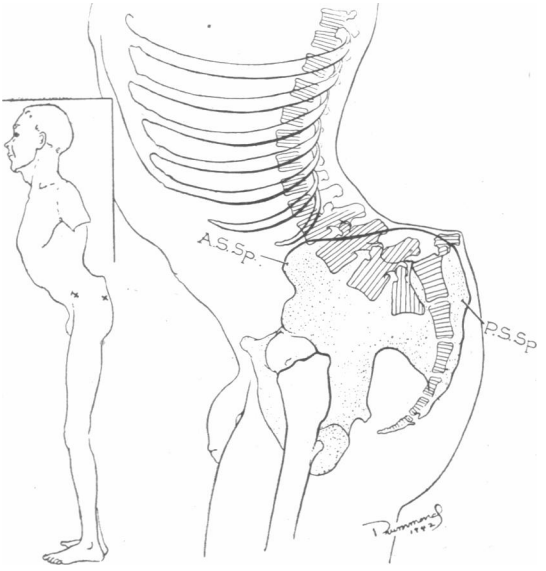

Fig. 15. Diagram to illustrate the separate elements in the deformity of spondylolisthesis. (1) Forward displacement of the body of the fifth lumbar vertebra. (2) Step kyphosis at spine of fifth lumbar vertebra. (3) Increased lordosis of lumbar spine. (4) Rotation of pelvis about a transverse axis so that sacrum is vertical, and (5) anterior superior spine is higher than posterior superior spine. (6) When deformity is great the trunk cannot be held erect.

If the forward slip is great, the trunk is shortened from above downwards, transverse folds appear about the waist and the lower ribs touch the iliac crests or disappear within the false pelvis. In extreme cases the deformity may be very great and very complex, as illustrated in Fig. 14. In the most severe degrees of slip, the body of the fifth lumbar vertebra slides completely off the top of the sacrum and comes to lie with its inferior surface applied to the anterior face of the sacrum.

The various elements in the deformity of spondylolisthesis are depicted in the diagram illustrated in Fig. 15. They may be summarised thus: (1) forward displacement of the body of the fifth lumbar vertebra; (2) step kyphosis of spines, that of the fifth being prominent; (3) increased upper lordosis of the lumbar spine; (4) rotation of pelvis about a transverse axis so that (5) the anterosuperior spine is above the level of the posterosuperior spine; and (6), when the deformity is severe, the trunk cannot be held erect over the legs even when the hip joint is fully extended; (7) the trunk settles down into the pelvis, the lower ribs touch the iliac crest and folds appear around the waist.

The defect of the neural arch which is the essential feature of spondylolysis may be unilateral or may be much more marked on one side than on the other. In either case the body may slip forward more on

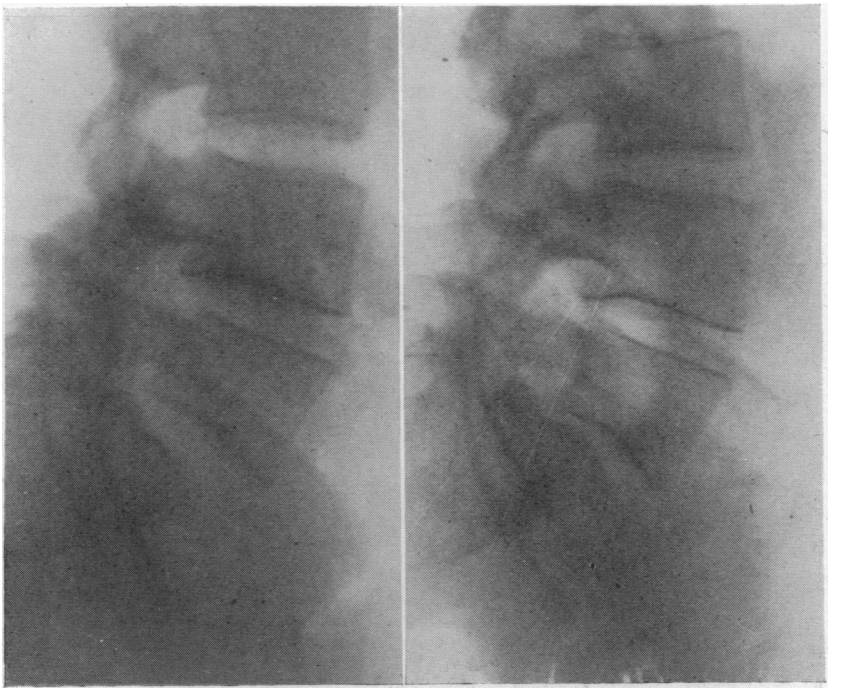

Fig. 16. (*a*) and (*b*). To illustrate progression of the deformity. (*a*) Lateral radiograph in 1941 of P. L., a 40-year-old medical officer at the time his symptoms commenced (*b*) Radiograph of P. L. in 1945 to demonstrate progression of the deformity.

one side than on the other. This initiates a type of lumbosacral scoliosis with compensatory curves above it, of which there were two examples in this group of 100 cases.

The progression of the spondylolisthesis may be slow and the circumstances under which many cases are diagnosed and treated may preclude actual observation of the progression of the deformity. On this ground and also on the ground that many cases first present themselves with symptoms at middle age or later (though with demonstrable displacement when first seen), it has been argued that the displacement is not progressive but is something which has been present since birth. However, when opportunity exists to observe patients with spondylolisthesis over a period of time, it is possible to demonstrate that the displacement of the body of the fifth lumbar vertebra upon the sacrum is progressive. Fig. 16 illustrates this point.

Diagnosis

With well-marked deformity, the diagnosis of spondylolisthesis is simple. When the deformity is inconspicuous the diagnosis may not be

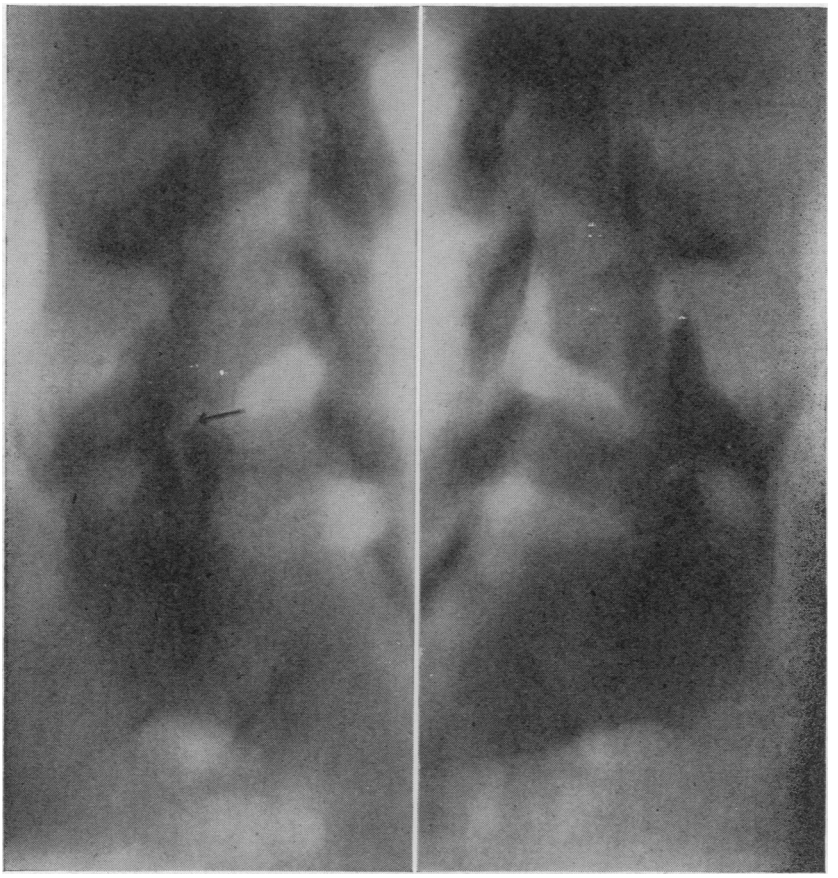

Fig. 17. Oblique laminograms, right and left. The arrow points to a unilateral defect in the left isthmus.

easy. The items of greatest value in reaching a diagnosis are (1) the history of pain low in the lumbar region ; (2) the addition of sciatica to the lumbar pain—if this is bilateral it is of particular significance and in severe cases peroneal palsy adds to its significance ; (3) the deformity, when it is present, and (4) the radiographic findings. The forward displacement of the body of the involved vertebrae can be recognised with certainty only in a good lateral radiograph. As a rule this projection also shows the defect in the neural arch. If the gap at the defect is slight and there is no forward displacement of the involved vertebral body, oblique radiographic projections are valuable to demonstrate the lesion, since only by this method can the X-ray be projected through the defect to reveal its presence (Fig. 3). Oblique laminograms are

particularly valuable (Fig. 17). The anteroposterior projection does not reveal the deformity clearly, though when the deformity is severe the outline of the body of the fifth lumbar vertebra, as though seen from above downwards, makes a characteristic picture.

Treatment

The basic principle of treatment in spondylolisthesis is fixation of the unstable vertebra. This fixation may be secured by the external application of a plaster jacket or a spinal brace, or by the more efficient internal fixation of lumbosacral fusion. Nice judgment is necessary to determine the treatment best suited to an individual patient. Some have few symptoms and are little disabled. Some have severe and progressive symptoms. Age is an important factor. As a general rule the younger patients should be operated upon even though their symptoms are not severe. Solid fusion can be anticipated and by this they can be spared a life-time of invalidism. In older patients operation should be undertaken more cautiously. Fusion is less easily secured. The risk is somewhat greater. The time which must be expended in postoperative fixation imposes a greater economic burden. It may be possible to adjust conditions of living so that less stress is placed upon the unstable vertebra and this, with a brace, may be all that is necessary to give them reasonable comfort.

Operative Treatment

The most effective treatment is lumbosacral fusion. If the lower lumbar spine is successfully fused to the sacrum, bridging the defective vertebra with an adequate mass of bone, the patient's symptoms disappear, his back again is strong and he is capable of hard work. Posterior fusion, which bridges together the spines and laminae, is best, since it permits greater flexibility of technique to meet special difficulties, provides a solid mass of bone and does not involve as great a risk as does the anterior body-to-body fusion through a transperitoneal approach.

Operation, however, is not to be undertaken lightly. The procedure is prolonged and is associated with some risk to the patient from hæmorrhage and shock, and occasionally from infection. It is the most difficult of all spinal fusions and demands the utmost in technical skill from the surgeon. Nothing short of perfect fusion will meet the need of the patient and this is by no means easy to attain. It is less likely to succeed after middle life than in youth and at any age the operation must be planned with precise regard to the fundamental principles of bone transplantation and executed with meticulous technique.

There is no one perfect operative technique. The anatomical circumstances vary in each case and in a manner which precludes rigid standardisation. There are, however, certain basic essentials which must be achieved. (1) The fusion must be massive since the whole weight of the body will be transmitted through it, together with all the stresses of movement and

effort. (2) The anchorage to the sacrum must be large, secure and quickly attained. (3) Anchorage to the vertebra above the lesion should be equally secure and broad, yet if possible it should be limited to the one vertebra immediately above the lesion. To extend it further accumulates stresses upon the graft and also upon the point of mobility immediately above the fusion. These may cause fracture of the graft or failure of fusion or arthritic changes due to sharply localised movement at the junction of the fixed and mobile segments of the spine. (4) The technique of fusion should permit such firm fixation of the grafts to the sacrum and to the lumbar spine as will assure a degree of internal splinting during the post-operative period which will resist those movements in the lumbosacral region which cannot be completely obliterated by any kind of external fixation. (5) There must be sufficient post-operative protection of the graft from stress to ensure fusion and to avoid fracture of the graft. This necessitates an adequate period of recumbency (four months) in the immediate post-operative period and protection by a brace for the first six months of ambulation. Though it would be very desirable to reduce the period of post-operative rest, it is futile to expect satisfactory fusion unless there is an adequate period of post-operative fixation. To shorten the period of post-operative recumbency risks the price of too high a proportion of failures of union. (6) The resumption of strenuous activity must be gradual to avoid the danger of too great stress, too soon, upon the graft before it has had time to be completely re-organised into living bone.

Our present operation for spondylolisthesis has evolved out of long experience and is designed to meet the above requirements. It is the most satisfactory procedure yet devised but should not be regarded as the last word. Probably it will be improved still further. The basic plan is to bridge the defective vertebra by fusion of the spines and laminae above the lesion to the sacrum by means of cortical tibial grafts, supplemented with cancellous bone. Two tibial grafts are placed on edge with their cancellous surfaces applied to the spinous processes and their deep edges to the laminae. They are fastened securely in place by sutures of stainless steel wire, tied with a special instrument (Harris, 1943). The lower ends are embedded in the sacrum. These grafts are sufficiently rigid and strong to support the unstable segment of the spine and to fix the operative field during the immediate post-operative period. They lend themselves to secure fixation to the sacrum and to the lumbar spinous processes. The addition of cancellous bone provides for the early development of new bone which will ultimately ensure a massive bridge of fusion. Cancellous bone alone or multiple fragment grafts do not give the fixation necessary to form a solid bridge. Too frequently such technique ends in pseudarthrosis.

If there is evidence of root pressure due to changes in the disc between L.5 and S.1, exploration of the disc and removal of the lesion should precede lumbosacral fusion.

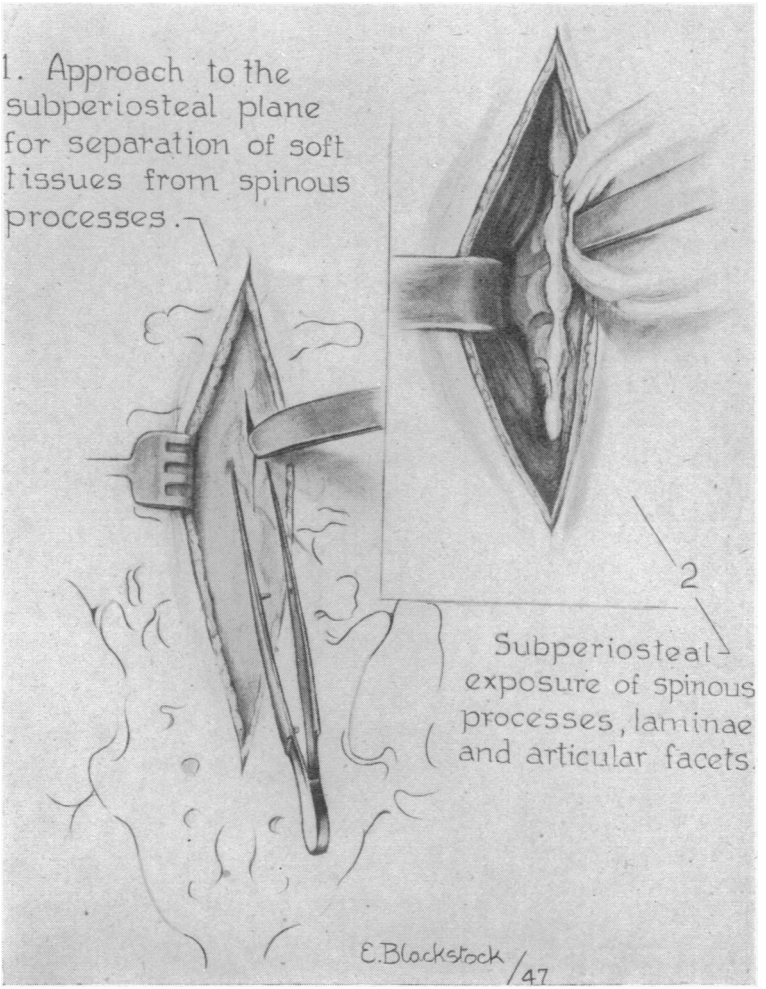

Fig. 18. Technique of the operation for spondylolisthesis. The soft tissues are first separated from the spines and laminæ by elevation in the subperiosteal plane. *Step* 1. The fibrous tissue attached to the tip of the spinous process is split to the bone and separation in the subperiosteal plane is commenced with a Bristow raspatory. *Step* 2. Once the subperiosteal plane is entered the muscles are wiped off by forceful packing with gauze.

The operative procedure is as follows and is illustrated by Figs. 18, 19 and 20.

The soft tissues are elevated from the spines and laminae by separation in the subperiosteal plane. It is important to enter this plane at the first step. To do so minimises hæmorrhage and simplifies separation of soft tissues from bone. To accomplish this, the soft tissues over the tip of

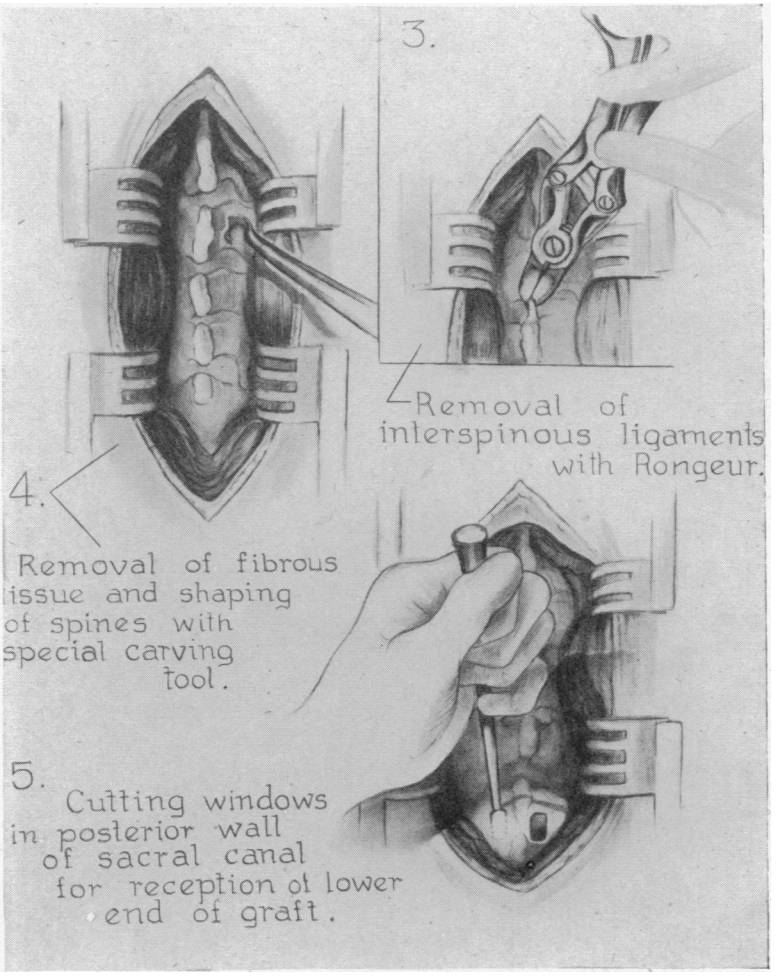

Fig. 19. Preparation of the field for the bone grafts. *Step* 3. Upper half of interspinous ligaments is removed with a rongeur, baring the bone of the spinous processes. This provides a space into which cancellous bone will be packed. *Step* 4. The spines and laminae are carefully denuded of periosteum using special carving tools. *Step* 5. Windows are cut in the posterior wall of the sacral canal for the reception of the lower ends of the tibial grafts.

the spinous process are divided down to bone with a single firm knife cut. This permits the subperiosteal separation of soft tissues to commence at the tip of the spinous process and to be carried rapidly down the side of the spinous process with a Bristow raspatory. A gauze strip packed firmly into this space using a Bristow raspatory with a wiping movement continues the subperiosteal separation quickly and with a

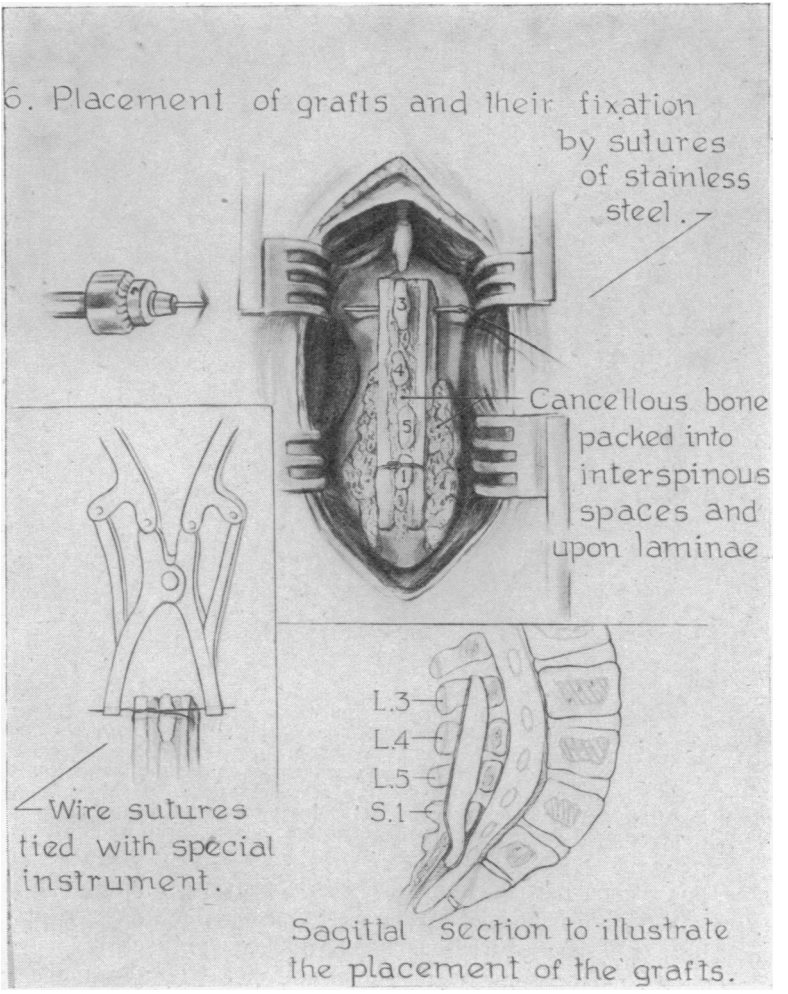

Fig. 20. *Step* 6. After suitable modelling the lower ends of the grafts are inserted into the windows in the posterior wall of the sacral canal. The upper end of the graft is then accurately applied to the spinous processes and laminae of lumbar vertebrae 3, 4 and 5. Cancellous bone is packed into the interspinous spaces and on to the denuded laminae. The tibial grafts are fastened securely in position by two sutures of stainless steel wire No. 20, tied in a square knot with a special wire-tying instrument.

minimum of hæmorrhage. Separation of soft tissues is continued till the spines, laminae and articular facets in the whole field are completely exposed. The bony surfaces, carefully and completely freed of soft tissues, are modelled to ensure close fit of the grafts by removal of irregularities with special instruments (Fig. 21). The interspinous

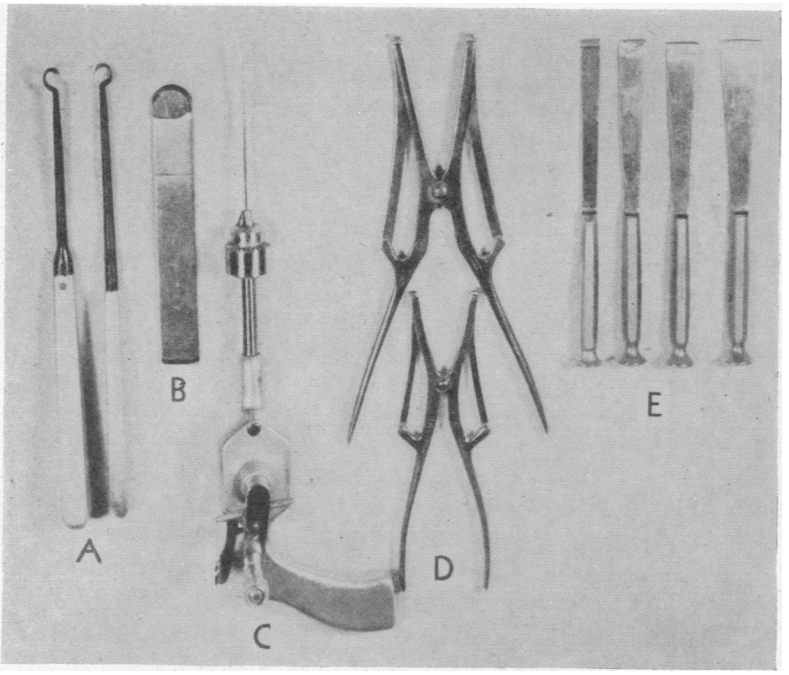

Fig. 21. Certain instruments of special design useful in the operation of lumbosacral fusion for spondylolisthesis. (*a*) Curved scrapers modelled after the tools used to "draw out" the core of the willow bucket of an artificial leg. Useful for cleaning the laminae and spines and carving them to shape. (*b*) Round-ended Swedish osteotome for quick and broad scraping of soft tissues from bases of spines and laminae. (*c*) Drill carrying eyed Kirschner wire by means of which the stainless steel wire is passed through the grafts and spinous processes. (*d*) Instruments to tie the knots in the stainless steel wire suture. (*e*) Thin osteotomes of various widths.

ligaments are then partially removed with a rongeur, taking with them the edges of the adjacent processes so as to ensure the exposure of bare bone. Into this space cancellous bone will later be packed.

Only rarely are the upper sacral spines sufficiently large to make them a satisfactory anchorage for the lower end of the graft. In most cases, to ensure firm fixation, the lower end of the graft is implanted into the sacrum. For this purpose windows are cut in the posterior wall of the sacral canal on either side of the first sacral spine. These windows are so fashioned as to leave a bridge of bone at the upper margin across which the graft may be levered to press its tip against the deep surface of the posterior wall of the sacral canal, and thus avoid impingement upon the sacral nerve roots.

A bone graft is removed from the subcutaneous surface of the tibia of sufficient length to provide two grafts for the operative field. As much cancellous bone as possible is removed with a large curette from the

upper end of the tibia. The tibial bone graft is divided into two equal portions. The lower end of each is modelled as indicated in Fig. 20 for insertion into the sacral window. The deep edge of the graft is modelled so that it fits down snugly upon the laminae from third or fourth lumbar to the sacrum ; this is important. There must be good contact with the laminae as well as with the spinous processes. When the grafts have been satisfactorily modelled, the lower ends are inserted into the windows cut for them in the posterior wall of the sacral canal and they are driven home with a few firm hammer taps. The upper half of each graft is then pressed into its bed against the spinous processes and the laminae. Cancellous bone is packed between the tips of the spinous processes in the space from which the interspinous ligament was removed. The grafts are held firmly in place with sequestrum forceps. With an eyed Kirschner wire a No. 20 gauge stainless steel wire suture is drawn through the upper ends of the grafts and the spine of the fourth (or third) lumbar vertebra, and tied with the wire-tying instrument. A similar suture is passed through the lower ends of the graft and the spine of the first sacral vertebra, if this spine is large enough to hold a suture. The remaining cancellous bone is placed in the angle between the deep edge of the graft and the laminae, concentrating it in the lumbosacral region. If the amount of cancellous bone is limited, it may all be placed on one side to ensure at least one adequate bridge of bone rather than two inadequate bridges. Cancellous bone from the ilium is used if necessary.

If any doubt exists of the security of the attachment of the lower ends of the grafts into the sacrum, they are still further held in place by passing a heavy Kirschner wire through the posterior projection of the wing of the ilium on either side, arching it backwards over the grafts in such a manner that they are pressed securely into their bed. A channelled instrument such as a small Kuntscher nail assists greatly in the placement of this wire. The projecting end of the wire is cut off close and the skin allowed to cover the cut end. This wire is removed under local anæsthesia at the end of four months when it has served its purpose.

The articular facets are not deliberately fused though they are exposed in the field of operation and the portion which projects posteriorly beyond the lamina is removed. To remove the cartilage of the facets and fill the defect with bone grafts adds materially to the length of operation without corresponding advantage.

Plaster shell and plaster spica have been abandoned as measures of post-operative fixation. Chief reliance is placed upon the strength, firm sacral anchorage and rigid fixation of the on-edge bone graft. Recently the Stryker frame has proved a valuable adjunct in post-operative care. It simplifies nursing of the patient and minimises movement in the field of operation, and stresses upon the graft during the period of fusion.

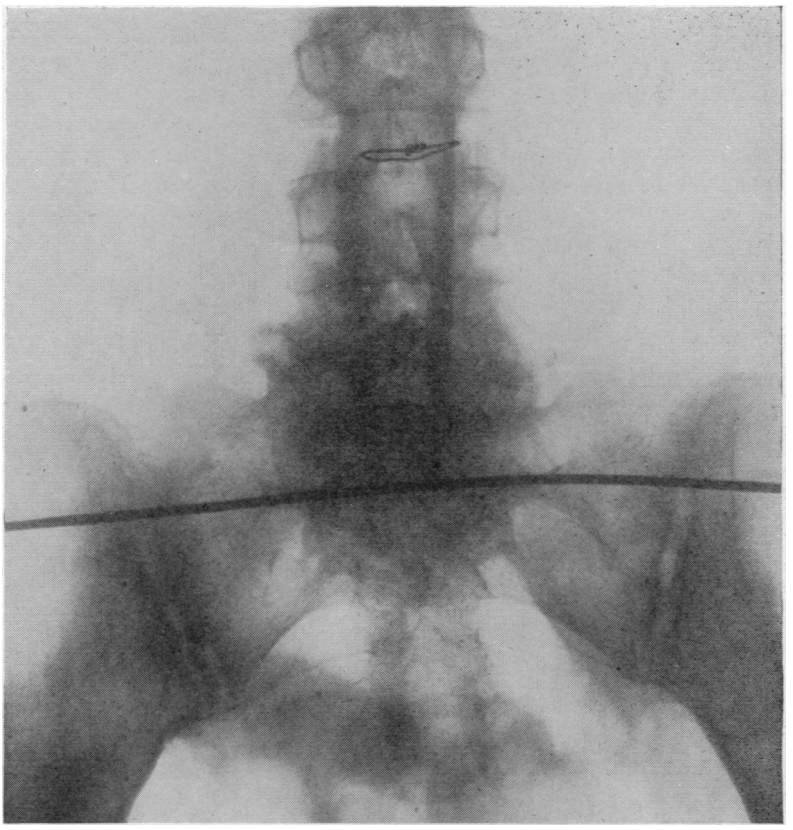

Fig. 22. For additional security a heavy Kirschner wire is passed transversely through the posterior projection of the wings of the ilia, arching over the grafts to press them down into their bed. The wire is subsequently removed.

Operative Correction of the Vertebral Displacement

An important accessory problem requiring operative management is the restoration of the displaced vertebral body to its normal position. If the amount of slip is small, the deformity is of little significance. But when the displacement is great, it becomes of itself a cause of disability, even after the spine has been stabilised by fusion. For example, the associated rotation of the pelvis with the disturbance it causes in the position of the legs in relation to the trunk will continue after fusion unless the displacement of the vertebral body can be corrected before operation (Fig. 13).

Correction of the deformity and replacement of the involved vertebral body to something approaching its normal relationship to the body

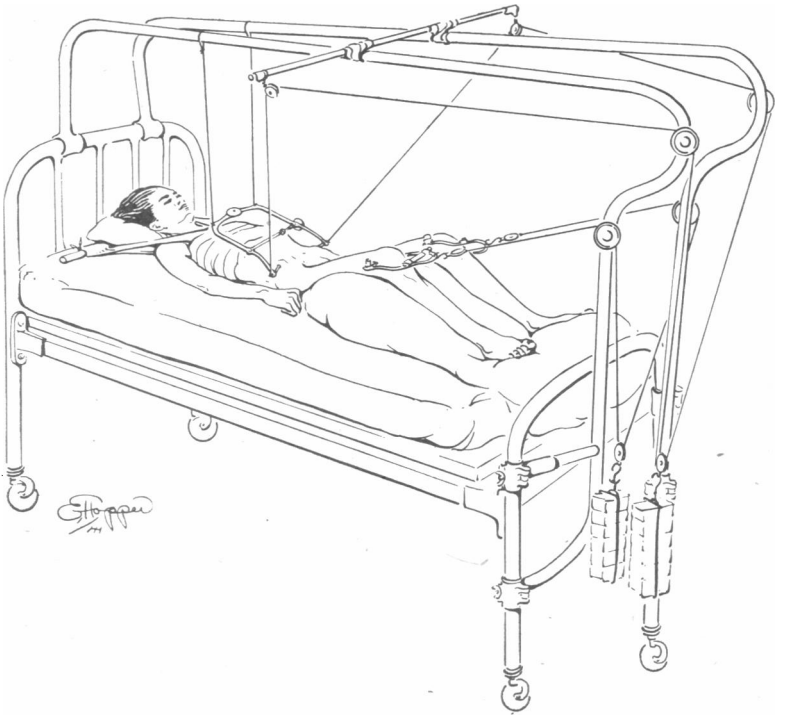

Fig. 23. .Drawing to illustrate the method of correcting the displacement in spondylolisthesis. The trunk is anchored to the head of the bed by the shoulder tails of a vest made of silence cloth fastened to the skin by mastisol and a snug bandage. Longitudinal traction is applied by means of Kirschner wires through the lower ends of both femora. The pelvis is then lifted forward by skeletal traction applied to the wings of the ilia.

below is less difficult than might be thought. A method which has been found effective is illustrated in Fig. 23. The trunk is anchored to the head of the bed by the shoulder tails of a vest made of silence cloth which has been fastened securely to the skin by mastisol and held in place by a firm bandage of flannelette. Strong traction is applied longitudinally by Kirschner wires through the lower end of each femur, the hips and knees being slightly flexed to permit the spreader of the Kirschner wire to clear the shin. The pelvis is then lifted forward by skeletal traction applied through the wings of the ilia near the antero-superior spines. In the case illustrated this has been achieved by Kirschner wires and spreaders. A more effective apparatus on the principle of the ice tongs has since been devised (Fig. 24), which simplifies the procedure and permits the retention, during the operation and in the post-operative period, of the correction which has been achieved by incorporating the traction tongs in plaster fixation.

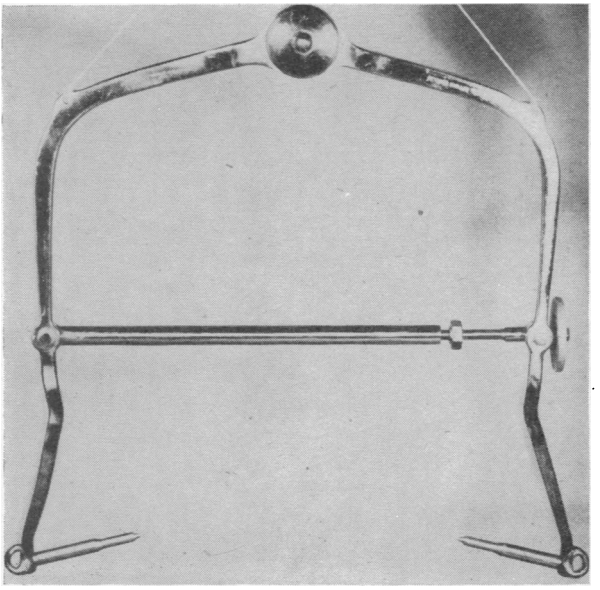

Fig. 24. The ice tongs used to apply skeletal traction to the pelvis to lift it forward.

The result which can be obtained by this method of correction is illustrated in Figs. 25 and 26. These are the radiographs of the patient whose deformity is illustrated by Fig 14. The reposition of the body of the fifth lumbar vertebra to its normal relationship to the sacrum has been remarkably successful. All of this correction was not maintained during the post-operative period because no attempt was made to continue the skeletal traction after operation. This does not detract from the importance of the principle that skeletal traction properly used can correct the deformity of spondylolisthesis.

Results of Operative Treatment of Spondylolisthesis

Generally speaking it can be stated that the operative treatment of spondylolisthesis cures the patient of his symptoms *if* solid fusion is obtained. But the " if " is a big one. The technical problems involved in planning and executing the right type of operation, in ensuring solid placement of the grafts, in maintaining stillness in the field of operation till fusion has occurred and in protecting the graft from undue stress until it acquires its maximum strength, are so numerous, so complex and so important that some technical failures are almost certain to occur. There are examples of various types in this series. These are not valid criticisms of the merit of operative treatment of spondylolisthesis. Rather they demonstrate the fact that the operation is difficult in its

Fig. 25. Correction of the displacement in spondylolisthesis. This is the radiograph of the patient illustrated in Fig. 14. The body of the 5th lumbar vertebra is displaced completely from the top of the sacrum and lies on the anterior face of the sacrum at the interspace between the first and second sacral segments. It has rotated through 90° so that its inferior surface is applied to the anterior surface of the sacrum.

execution and demanding in its post-operative care. If solid fusion is obtained from operation, the improvement it accomplishes is dramatic. Often it amounts to restoration of normal function (Fig. 27).

Of the 100 cases which form the basis of this essay, 67 were treated by operation. Of these 56 were cured of their symptoms and enabled to lead an active and normal life.

Poor Results and Complications

The operative management of spondylolisthesis is so definitely a treatment of choice rather than of necessity that any result short of perfection

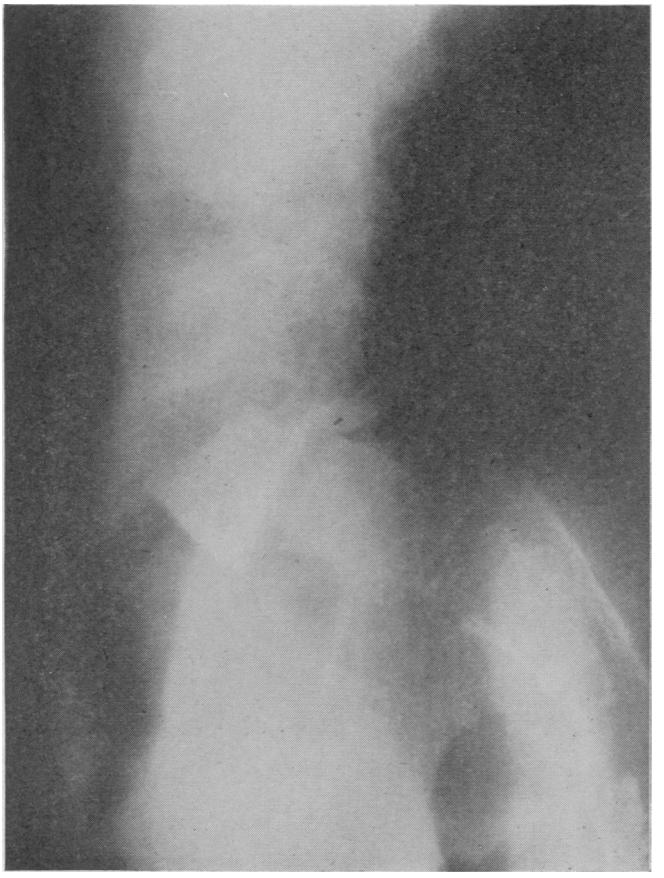

Fig. 26. The result obtained by skeletal traction (see Fig. 23) applied to the deformity shown in Fig. 25.

mars the success. Some mention of imperfect results and possible complications, therefore, is necessary.

The most frequent cause for an unsatisfactory result from operation in spondylolisthesis is failure to obtain fusion of the lumbosacral region. This can be caused by failure of the graft to unite to the sacrum or to the spinous processes of the lumbar vertebrae, by imperfect fixation of the grafts to their bed so that contact is poor, by undue movement of the grafts in their bed during the post-operative period, by a small and inadequate bridge of bone, or by fracture of the graft with subsequent non-union at the site of fracture. Most such failures can be attributed to technical imperfections in the operation which can be eliminated by improved operative technique and experience.

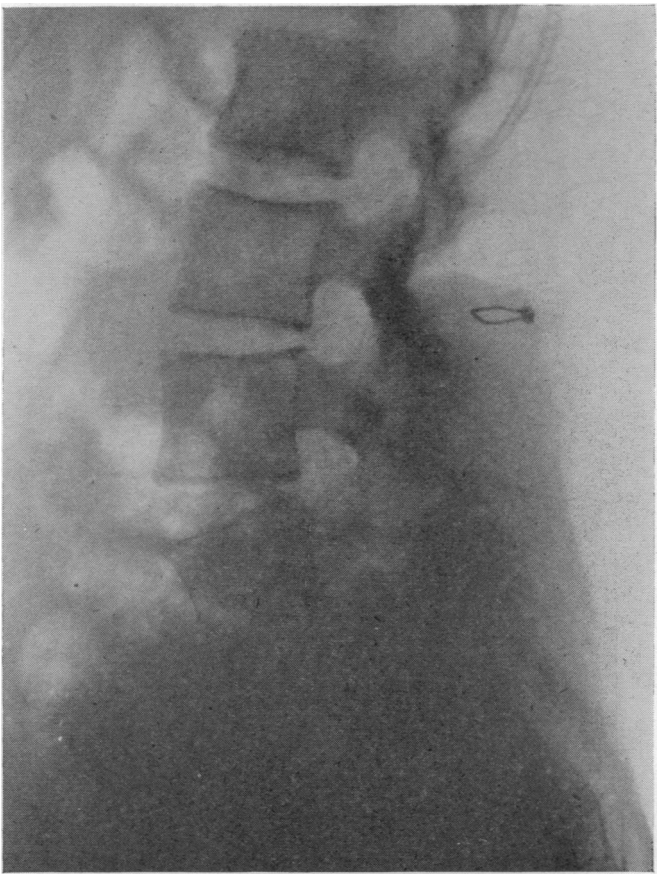

Fig. 27. Lateral radiograph to illustrate the successful result to be obtained by the operative technique illustrated in Figs. 18, 19, and 20. A massive bridge of bone extends from the spine of the third lumbar vertebra to the sacrum. Fig. 5 is the pre-operative radiograph of this patient.

A small group have disability despite solid fusion because of the persistence of a major degree of deformity.

Further potential complications are hæmorrhage and shock, infection, thrombophlebitis, stress fracture of the tibia from which the graft has been taken and nephrolithiasis due to recumbency. *Hæmorrhage and shock* can be guarded against by care during operation or can be corrected by appropriate measures. To-day fortunately *infection* is an almost non-existent problem. Improved operative technique and the antibiotic agents have virtually eliminated this complication. There is great merit in the local use of antibiotic agents for prophylaxis against infection in this, as in all operations of great magnitude upon bone. *Thrombo-phlebitis*

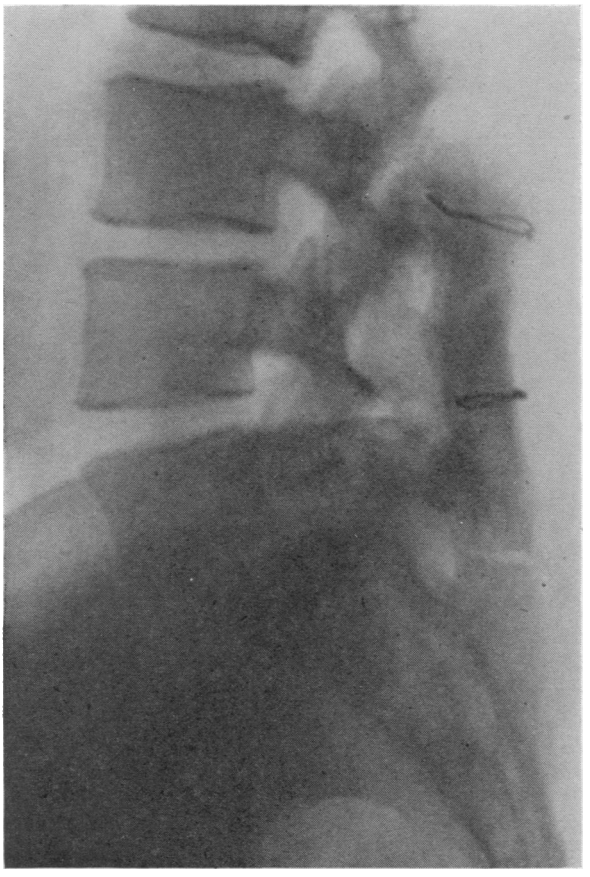

Fig. 28. Lateral radiograph of patient B. W. with spontaneous fracture of the graft, thirteen months after operation.

is an ever present hazard, capable of marring the most perfect operation. Since it almost invariably develops in the leg from which the bone graft has been removed, one cannot escape the conclusion that the trauma of this procedure and the subsequent confinement of the limb in a dressing are major factors in the development of thrombophlebitis. There were five cases of thrombophlebitis in the 67 operations in this series of 100 cases, two of them complicated by pulmonary embolism. While no death occurred from thrombophlebitis or pulmonary embolism, the risk is appreciable and the potential late disability materially detracts from the perfection of the result. Every precaution should be taken to prevent the development of thrombophlebitis by minimum trauma to the extremities, by the avoidance of tight dressings and the early active

Fig. 29. Lateral radiograph of B. W. 22 months after Fig. 28. Solid spontaneous union of the fracture.

movement of the limb. If it develops in spite of precautions, anti-coagulant therapy should be initiated immediately and continued until all evidence of active thrombophlebitis has subsided. *Stress fracture* of the tibia from which the graft has been taken is relatively common but is seldom recognised. The patient who complains of persistent soreness in the shin after he commences to walk and who has localised tenderness at the same point almost certainly has a stress fracture. Careful radiography will reveal the localised deposit of subperiosteal new bone and, if taken at the appropriate time, will also show the transverse hair line break in the tibial cortex. The size of the graft removed from the tibia, particularly its width, doubtless has something to do with the development of stress fracture. Fortunately the disability from stress fracture is not great and the outcome is always satisfactory. Though uncomfortable, the patient

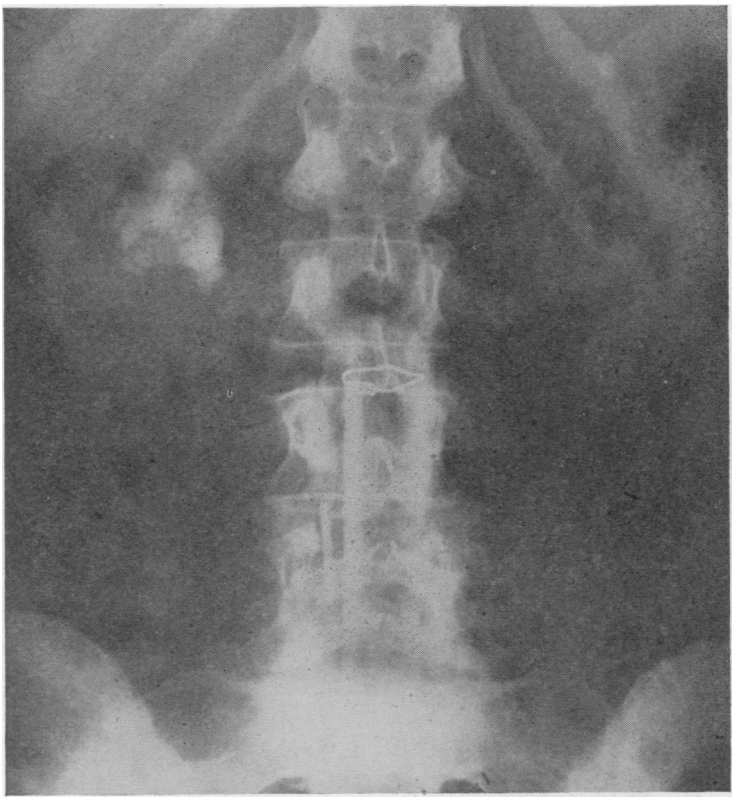

Fig. 30. Nephrolithiasis complicating operative treatment of spondylolisthesis. Right kidney pelvis filled with stones, one stone in left kidney, after four months of recumbency. There were no stones present before operation.

can continue to walk and in due time spontaneous recovery occurs. *Nephrolithiasis* may develop in the post-operative period of spondylolisthesis as it may in any condition which involves prolonged and unremitting recumbency, especially in the supine position. It can be prevented almost completely by daily turning of the patient. For this purpose the Stryker turning frame is particularly valuable, since it permits easy turning of the patient without disturbance of the field of operation.

Some examples of failure to achieve success by operation are illustrated by the following cases :—

Separation of the graft from the spinous process of the third lumbar vertebra. A 30-year-old soldier with spondylolisthesis showing moderate slip was operated upon. Double tibial bone grafts " on edge " were applied from the spine of the third lumbar to the sacrum. The lower ends of the grafts were embedded in windows in the sacrum. A quantity of cancellous bone was implanted on the laminae of lumbar vertebrae four and five and on the sacrum. There

was difficulty in fitting the tibial grafts down so that the lower edges touched the laminae. Good fixation was obtained by a suture of stainless steel wire through the upper end of the grafts and the spine of the third lumbar. The patient was recumbent for four months. After he became active he complained persistently of pain in his back. A second operation showed that the tip of the spine of the third lumbar vertebra had been avulsed from its base by the force exerted upon it by the grafts which were sutured to it.

Fracture of the graft. A 40-year-old nurse, obese, with spondylolisthesis was operated upon and the lesion fused by a double tibial bone graft placed on edge from lumbar three to the sacrum into which the lower ends of the graft were embedded. Cancellous bone was added. Post-operative course was uneventful. She was at work again in six months. Thirteen months after operation, while dressing, she stooped to fasten her shoes. There was an audible crack originating in the back and pain was felt there instantly. Radiograph (Fig. 28) showed a transverse fracture of the graft between the spine of the fifth lumbar and that of the first sacral. Symptoms persisted for about four months, gradually diminishing. Radiograph at the end of 22 months (Fig. 29) showed solid union of fracture.

Nephrolithiasis due to recumbency. Mrs. D. D., 29 years old, with spondylolisthesis and moderate slip, was operated upon and a lumbosacral fusion performed from lumbar two to sacrum. She was continuously recumbent for four months following operation. On the day that she was first turned over to remove her stitches and change the dressing, she had an attack of renal colic. Radiograph (Fig. 30) revealed the right kidney pelvis full of stones and a small one in the left kidney pelvis. Both sides had been clear of stones before operation. The stones in the right kidney became impacted at the uteropelvic junction, causing obstruction behind which infection became implanted. This necessitated pyelotomy and, finally, nephrectomy.

It is important to establish a post-operative routine in which the patient is turned daily on his face to permit adequate emptying of the kidney pelvis.

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