THE ETIOLOGY OF SPONDYLOLISTHESIS

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With a Special Investigation by

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The history of the recognition of spondylolisthesis and of the investigation into its cause makes interesting reading. Herbiniaux (1782), a Belgian obstetrician, was possibly the first to draw attention to this lesion, although in 1741 Andry had described the cause of a hollow back as a warping of the spine inwards. Originally attention was attracted to it as a cause of obstruction in labour. During the early part of the nineteenth century a few workers found specimens of gross displacement. From anatomical dissections they concluded that it was due either to a congenital deformity or to some disease in the lumbo-sacral disc. At that time it was described as a luxation of the lumbo-sacral joint. Kilian (1854) thought that this term was not correct. He pointed out that it was due to a slow displacement of the last lumbar vertebra and coined the term spondylolisthesis. Up to 1855 those interested in the subject seemed to be satisfied to accept the condition as a slow slipping of the last lumbar vertebra due to superimposed body weight. But Robert (1855), by careful dissection and freeing the fifth lumbar vertebra of all soft tissues, showed that it was impossible for the vertebra to slip so long as the neural arch remained intact. He demonstrated that if the neural arch was cut the vertebra was free to slip. This is the first indication of the focusing of attention on a lesion of the neural arch. Suspicion that there was such a lesion was confirmed in 1858 by Lambl, who demonstrated discontinuity in the pars interarticularis in a few cases. Hartmann (1865) noticed that although the body of the vertebra slipped forward the spinous process remained in the same place, thus indicating that there was a division in the neural arch. Neugebauer (1881) stated that the deformity consisted of an elongation and angulation of the sagittal axis of the vertebra mainly in the interarticular portion, but made no mention of a loss of continuity of the bone. This in the light of modern knowledge proves to be correct, for it is evident that the only cases of spondylolisthesis which these early workers found at post-mortem examination were those of gross displacement—examples of a group exhibiting marked displacement without discontinuity of bone. Controversy then arose about the cause of this elongation in the pars interarticularis and confusion followed the discovery in some cases of a break in continuity, for it was not apparent at the time that two entirely different pathological conditions were under discussion. Neugebauer (1888), then becoming engrossed in this subject, travelled through Europe examining anatomical specimens of spinal columns. He discovered in some a lesion of continuity in the pars interarticularis, with or without forward displacement of the vertebral body. In ten specimens of gross displacement which he termed spondyloptosis he found fractures of the sacral facets or lesions of the interarticular portion of the neural arch. At first he thought that trauma was the most likely cause of the interarticular defect, but he later became persuaded that it was congenital, from an abnormality of ossification. The theory of abnormal ossification of the pars interarticularis was not acceptable to Lane (1893), who suggested that spondylolisthesis was due to modification of the interarticular part of the fifth segment by pressure from the sharp edge of the inferior articular process of the fourth lumbar segment above and from that of the superior sacral process below. This theory has been supported by others (Capener 1931, Meyer-Burghoff 1931).
With the advent of radiology during the early part of the century the study of spondylolisthesis tended to become more radiological than anatomical. At first the radiographs were not clear enough to show a defect in the pars interarticularis, but as their quality improved more and more attention became focused on that particular lesion. So important has this lesion become as an etiological factor in spondylolisthesis that it has been defined by some workers as the basic feature of spondylolisthesis itself, so that vertebral slipping without an interarticular defect has not been classed as true spondylolisthesis. Subluxation at the lumbo-sacral joint, where there is generally no such lesion, has been excluded, particularly by authorities in Europe, from classification as true spondylolisthesis. Spondylolisthesis between the fourth and fifth lumbar vertebrae without a lesion in the neural arch has been termed pseudospondylolisthesis by Junghanns (1930). But it is important to recall that the original term spondylolisthesis introduced by Killan (1854) indicated a slipping of a vertebra and not a lesion of continuity in the neural arch. That the meaning of the original term has been lost seems to have been one of the causes of confusion in understanding the true nature of this condition and the different types that occur. The typical lesion of the pars interarticularis is correctly described as spondylolysis whether or not the vertebral body has slipped.

A CLINICAL STUDY OF THE ETIOLOGICAL FACTORS

During the last fifteen years a clinical, radiological and in some cases surgical, study of 319 cases of spondylolisthesis has been made. It has become obvious during this study that there are five different types of spondylolisthesis. Acute fracture-dislocation with forward displacement caused by severe trauma, an uncommon injury in the lower lumbar spine, has not been included, nor has the mild backward displacement known as retropondyloysis.

In sorting out the various groups the three main possible causes, namely deficiency of the facets, deficiency of the neural arch and structural weakness of bone have been taken into account and have been the ruling factors in determining the different groups; sub-division of each of the first two groups has given five in all. So well defined have these groups become that it is evident that in the three commonest, where there are sufficient cases to make a comparative study, a clear and characteristic clinical picture evolves.

BIOMECHANICAL ASPECTS

The structure of the lumbo-sacral spine in the erect posture is such as to give a constant downward and forward thrust to the lower lumbar vertebrae. This is clearly demonstrated in the spine of a six-year-old girl affected with osteogenesis imperfecta (Fig. 1). The interarticular parts of the neural arches have been little affected but the pedicles have become markedly elongated at the fifth and fourth lumbar levels, moderately so at the third and slightly so at the second and first lumbar levels, showing that the thrust fades out about the higher levels. The extent of the thrust is exposed in this case by general weakness of bone.
force is usually exposed at only one level. The "caving in" to it results in spondylolisthesis. At this point it is appropriate to consider the structural mechanism which consolidates the lumbar spine to prevent such an occurrence.

The tendency to forward slipping is constant and is counteracted by: 1) adequacy of facets; 2) intact pedicles and neural arches; 3) normal bone structure (Fig. 2). The mechanism as a whole is consolidated by integrity of the soft tissue. A deficiency in any one of these three is liable to allow forward slipping, especially if the soft tissues binding the affected vertebrae are faulty.

In theory then the possible causes of spondylolisthesis may be: 1) defect of facets, congenital or acquired; 2) defect of the neural arch or pedicle, congenital or acquired; 3) structural inadequacy of bone. It is interesting that the cause of spondylolisthesis most widely accepted in the past has been a congenital defect in the neural arch, but in this series such a conception is the only one among the possible theoretical causes listed above that seems to be non-existent. During this study the mechanism of slipping in each group became evident, but the nature of the defect in the pars interarticularis remained unproven.

The normal lumbo-sacral joint and the types of spondylolisthesis. (Note that spondylolisthesis of Group IV shown here at the lumbo-sacral level, is most common at the lumbar 4–5 level.)

The possible causes of spondylolisthesis and the clinical material on which this study is based are summarised in Tables I and II. The types of spondylolisthesis are illustrated in Figure 3 and their incidence with regard to age and sex in Figures 4 and 5.
The sex incidence of the three commonest types of spondylolisthesis.

The age incidence at the time of diagnosis of the three commonest types of spondylolisthesis.
DEFICIENCY OF FACETS

CONGENITAL SPONDYLOLISTHESIS (GROUP I)

Synonyms: Lumbo-sacral subluxation, spondyloptosis (Neugebauer 1888)

There were sixty-six patients, twenty male and forty-six female, in this group. Some authorities have excluded this type of slip from classification as spondyloisthesis although instances of it appear in most monographs on the subject. It is not a simple subluxation:

<table>
<thead>
<tr>
<th>Theoretical cause</th>
<th>Nomenclature</th>
<th>Group</th>
<th>Occurrence in practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deficiency of facets:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congenital</td>
<td>Congenital</td>
<td>I</td>
<td>Frequent</td>
</tr>
<tr>
<td>Acquired</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fracture</td>
<td></td>
<td></td>
<td>Not observed</td>
</tr>
<tr>
<td>Degeneration</td>
<td>Degenerative</td>
<td>IV</td>
<td>Frequent</td>
</tr>
<tr>
<td>Defect of pars interarticularis:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Congenital</td>
<td></td>
<td></td>
<td>Believed non-existent</td>
</tr>
<tr>
<td>Acquired</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute fracture</td>
<td>Traumatic</td>
<td>III</td>
<td>Rare</td>
</tr>
<tr>
<td>Spondylosis</td>
<td>Spondylolytic</td>
<td>II</td>
<td>Common</td>
</tr>
<tr>
<td>Structural defect of bone</td>
<td>Pathological</td>
<td>V</td>
<td>Rare</td>
</tr>
</tbody>
</table>

The numbering of the groups in this way seems a little confusing, but it has been thought unwise to depart from the system suggested by Newman (1955). Each group has been given a name thought to be most descriptive of its supposed etiology.

TABLE II

THE DISTRIBUTION OF 319 CASES OF SPONDYLOLISTHESIS IN THE FIVE GROUPS

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of cases</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (Congenital)</td>
<td>66</td>
<td>20</td>
<td>46</td>
</tr>
<tr>
<td>II (Spondylolytic)</td>
<td>164</td>
<td>93</td>
<td>71</td>
</tr>
<tr>
<td>III (Traumatic)</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>IV (Degenerative)</td>
<td>80</td>
<td>22</td>
<td>58</td>
</tr>
<tr>
<td>V (Pathological)</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>319</td>
<td>142</td>
<td>177</td>
</tr>
</tbody>
</table>

it is a fundamental "caving in" of the lumbo-sacral area, with resulting deformity of the last lumbar vertebra and the upper part of the sacrum. In this group there is likely to be a major degree of slip; the condition is obvious at post-mortem examination and it is liable occasionally to cause obstruction during labour. Spondyloisthesis of this type was recognised and carefully described by the original workers in pre-radiological days and rightly was thought to be due to congenital defect.

This defect is constant: there is deficient development of the sacral neural arches, especially the first, with deficiency of the superior sacral facets. Owing to this deficiency the
sacrum cannot withstand the thrust of the last lumbar vertebra which gradually slips forwards and downwards over the top of the sacrum, its inferior facets wearing away and grooving the remnants of the superior sacral facets, with a glacier-like, slow but persistent movement. The inferior facets of the last mobile vertebra ride over or between the sacral remnants. The spinous process is carried forward and comes to rest on the fibrous defect of the first sacral neural arch, which it may indent. Here it stops, but in the major degrees of displacement the vertebra continues to slip by widening (or lengthening, according to the view taken) of the neural arch. The pars interarticularis, although attenuated and bending downwards, generally remains intact. This description agrees with that given by two early authorities. Neugebauer (1881) described spondylolisthesis as an elongation and angulation of the sagittal axis, mainly

THE JOURNAL OF BONE AND JOINT SURGERY
in the interarticular portion. Chiari (1892) believed that the condition was due to abnormal conditions in the region of the lumbo-sacral articular processes allowing the whole of the last lumbar vertebra to slip forwards.

**FIG. 9**
Natural stabilisation in spondylolisthesis. Specimen from the Museum of University College Hospital, showing the attempt at stabilisation by anterior buttressing.

Thus the essential points in defining this group are: 1) slipping of the last lumbar vertebra on the sacrum; 2) sacral spina bifida and deficient development of the superior sacral facets (Fig. 6); 3) giving way of the lumbo-sacral facets; 4) attenuation of the pars interarticularis (Fig. 7).

In thirty-two of these sixty-six cases there was a degree of slip of more than half the diameter of the vertebral body. In others the lumbo-sacral junction had become stable as slipping had ceased. In cases of very severe slip the body of the last lumbar vertebra may come to lie in front of the sacrum (Fig. 8).

**Secondary phenomena**—As the vertebra grinds its way forwards and downwards hugging the sacrum the lumbo-sacral disc becomes destroyed and the cartilage of the zygo-apophysial joints is worn away. It is not surprising therefore that occasionally spontaneous bony fusion takes place. This has been seen in a few cases and could be described as a natural cure of the instability (Figs. 9 and 10). Another attempt by nature to stop the process is the formation of a buttress of bone from the anterior aspect of the first sacral vertebra.

The pars interarticularis occasionally breaks. This is not surprising in
an attenuated piece of bone under stress, but this lesion must be accepted as a secondary phenomenon since it only occurs in a minority of cases.

In those cases with a severe degree of slip the cauda equina and the first sacral roots in particular are liable to be stretched in an elongated S bend between the neural arches of the last two lumbar vertebrae anteriorly and the knob of the back of the first sacral body posteriorly. When this stretching occurs to a degree that the nerve tissues are unable to withstand, a clinical crisis develops and it is at this stage that the patient is liable to seek medical advice.

The clinical crisis—This crisis has been observed in ten patients, seven girls and three boys, all between the ages of ten and eighteen. It is not difficult to imagine that some factor such as trauma, growth or the commencing secretion of the maturing hormone, loosens the articulations and allows an extra degree of slip. The patient comes with a rigid lumbar spine and spastic hamstrings and often with scoliosis (Fig. 11). Sometimes there are neurological signs indicating interference with the cauda equina or the first sacral roots. Myelography shows distinctly the narrow isthmus running between the two lowest lumbar neural arches and the top of the sacrum (Fig. 12). A recent article (Phalen and Dickson 1961) describes "Spondylolisthesis with tight hamstrings" and this term presumably refers to the same type of clinical picture. The two children whose cases are described were of the age group indicated here. Their radiographs show a severe degree of the congenital type of spondylolisthesis. The scoliosis which occurs acutely at the onset of this crisis is of a "sciatic" type, due presumably to a reflex spasm from interference with nerve tissue. Another type of scoliosis akin to idiopathic lumbar scoliosis occurs in these patients. It is not connected with pain and it is presumably due to an uneven degree of slip on the two sides.

Myelography in congenital spondylolisthesis. The narrow isthmus is seen passing between the two lowest lumbar neural arches and the top of the sacrum.
Findings at operation—The findings at operation are characteristic. There is a fibrous defect of one or more neural arches of the sacrum, in particular the first. The lumbo-sacral zygo-apophysial joints can be seen to have given way. The spinous process of the last lumbar vertebra lies on the fibrous defect and it and the rest of the neural arch is firm, not loose as in the most common type of spondylolisthesis (Fig. 13). If the laminae are removed the first sacral roots and cauda equina are found to be stretched between the neural arches of the fourth and fifth lumbar vertebrae anteriorly and the back of the first sacral vertebra posteriorly.

Fig. 13
Drawing of operation findings in a case of congenital spondylolisthesis. The lumbo-sacral zygo-apophysial joints have given way, and the spinous process of the last lumbar vertebra lies on the fibrous tissue replacing the neural arches of the uppermost segments of the sacrum.

DEGENERATIVE Spondylolisthesis (GROUP IV)
Synonyms: Pseudospondylolisthesis (Junghanns 1930)

Spondylolisthesis with intact neural arch (Macnab 1950)

There were eighty cases, twenty-two male and fifty-eight female. In this group the slipping is due to an acquired deficiency of the facets. It was described by Junghanns (1930) and by Schmorl and Junghanns (1932). Junghanns had stressed his desire to use the term spondylolisthesis for slipping caused by any lesion of the pars interarticularis. He chose to reserve the term true spondylolisthesis for cases of slipping caused by a congenital lesion of this part of the neural arch, and so coined the term pseudospondylolisthesis to designate the group with intact neural arch. Macnab (1950), quite rightly it seems, suggested that pseudospondylolisthesis was not a satisfactory term and suggested the designation "spondylolisthesis with intact neural arch." Since it is not the only type of spondylolisthesis with intact neural arch the term degenerative spondylolisthesis, descriptive of its essential pathology, has been used to designate this group.

Junghanns's (1930) original series was of fourteen cases, eleven female and three male, all between the ages of fifty-six and eighty-seven. He noted that the slipping most commonly occurred between the fourth and fifth lumbar vertebrae and that there were invariably marked osteoarthritic changes in the zygo-apophysial joints. The findings in this series were similar to those of Junghanns (Table III).

The essential points are the forward displacement of a lower lumbar vertebra, nearly always at the fourth lumbar level. It is nearly three times more common in women and has not been seen in patients under forty. The whole vertebra slips forwards without any further modification and there is notably no lesion of the pars interarticularis. Marked osteoarthritic changes are invariably present in the zygo-apophysial joints. In this group the incidence of symptoms and signs suggesting involvement of nerve tissue is the highest. Either the fifth lumbar roots or less commonly the cauda equina are involved. Five patients in this group who first came because of backache showed no slip in their original radiographs but subsequently...
the characteristic type of spondylolisthesis developed (Figs. 14 to 16). This must be accepted as certain evidence of an acquired displacement. It is also interesting that in many patients there was a long history of backache dating from the third or fourth decade. This, with the

![Figure 14](image1.png)

**Fig. 14**

Progression of slip in degenerative spondylolisthesis. Figure 14—Radiograph of lower lumbar spine of a woman, showing degenerative changes but no slip. Figure 15—Radiograph of the same patient fifteen years later. Slip now evident. Figure 16—Five years later: marked degree of slip now present.

fact that slipping was never seen in a patient under forty, suggests that a soft-tissue lesion precedes the displacement for a considerable period.

Measurements of the radiographs in this series studied for as long as fifteen years show an average slip of one-twelfth of an inch (2 millimetres) every four years during the progressive
period, but the slip was never observed to go farther than a quarter of the diameter of the vertebral body, which agrees with a similar observation made both by Junghanns (1930) and by Macnab (1950). It was noted also that the degree of development of the neural arches and spinous processes of the lumbar spine and sacrum of this group as a whole was of a high order in that the incidence of bony defect was considerably lower than the average.

TABLE III
DEGENERATIVE SPONDYLOLISTHESIS. AGE AND SEX INCIDENCE IN PRESENT SERIES COMPARED WITH THOSE IN JUNGHANN'S (1930) SERIES

<table>
<thead>
<tr>
<th></th>
<th>Junghans (1930)</th>
<th>Newman (1963)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of all cases of spondylolisthesis studied</td>
<td>60</td>
<td>319</td>
</tr>
<tr>
<td>Total in Group IV (Newman)</td>
<td>14 (23.3 per cent)</td>
<td>80 (25.1 per cent)</td>
</tr>
<tr>
<td>Males</td>
<td>3 (21.4 per cent)</td>
<td>22 (27.4 per cent)</td>
</tr>
<tr>
<td>Females</td>
<td>11 (78.6 per cent)</td>
<td>58 (72.6 per cent)</td>
</tr>
<tr>
<td>Range of age (years)</td>
<td>56-87</td>
<td>40-91</td>
</tr>
</tbody>
</table>

Junghanns (1930) admitted that he had no clear conception of the essential cause of this condition but suggested that it might be due to a congenital increase of the angle between the pedicle and the axis of the inferior articular facet. He had observed that this angle was greater in the slipping vertebral than in its neighbours. Macnab (1950), accepting this hypothesis of a congenitally increased angle, suggested that the forward slipping occurred as a result of overriding of the facets, a phenomenon secondary to the increased angle. In this series a careful study has been made of the radiographs and the findings at operation in fifteen cases. Neither the increase of the pedicle-facet angle nor the overriding of the facets has been observed. It has been seen in all cases at operation that the inferior articular facets of the slipping vertebra, exhibiting severe degenerative change, have ground their way between the superior facets of the vertebra below in a forward direction but that owing to the anterior hook of the superior facets (Macnab 1950), the degree of slipping is halted before it becomes severe.

THE MECHANISM OF SLIPPING IN DEGENERATIVE SPONDYLOLISTHESIS

K. H. STONE

Many investigators (Lambl 1858, Neugebauer 1881, Chiari 1892 (quoted by Friberg 1939), Junghanns 1930) have noted that displacement can occur in the absence of a bony defect in the neural arch. Junghanns's contention that the primary defect was an increase of the angle between the pedicle and inferior articular facet of the slipping vertebra was supported by Macnab (1950) who in one case observed slipping without radiographic evidence of degenerative change (Fig. 17). Macnab thought that the alteration of the angle allowed forward subluxation of the upper vertebra with overriding of the facets (Fig. 18).

Newman (1955) described forty-six cases of this type of spondylolisthesis which he called Group IV. Operation had been done in five cases and in each it was found that "the facets of the vertebra above had slipped between the facets below owing to severe degeneration of the joint surfaces" (Fig. 19).

In order to determine 1) whether an increase in the angle between the pedicle and the pars interarticularis exists and 2) whether a progressive increase in this angle accompanies slipping, a study has been made of the radiographs showing this type of displacement. Seventy-five lateral radiographs of forty-five patients have been studied. In forty-two the slip was between the fourth and fifth lumbar vertebrae: in two between the third and fourth and in one between the fifth and sixth.

The pedicle-facet angle—The angle measured was that formed at the intersection of a line drawn at right angles to the anterior border of the body through the pedicle and a second line bisecting the...
upper and lower borders of the pars interarticularis (Fig. 20). This angle was measured in the slipping vertebra and in the vertebra above and in that below. It was not found possible to define the plane of the posterior intervertebral joint accurately enough to use it as the second line of reference, although this would have been more desirable.

Because of the overlying bone shadows it was more difficult and almost certainly less accurate to measure the angle in the fifth lumbar vertebra than in those above. This is shown by the fact that the range of measurements for the fifth lumbar vertebra (93 to 145 degrees) is much wider than that of the measurements for the third (107 to 140 degrees) and for the fourth lumbar vertebrae (100 to 147 degrees). The average angle for the third lumbar vertebra was 122.4 degrees, for the fourth lumbar 122.3 degrees and for the fifth lumbar 119.9 degrees. Thus the angle in the slipping vertebra was no greater than that in the vertebrae immediately above and below it.

**Effect of progressive displacement on the pedicle-facet angle**—In twelve cases showing displacement between the fourth and fifth lumbar vertebrae an increase in the amount of slip was seen in radiographs taken at intervals varying from two to nineteen years (average seven years) after the first examination. It was thought possible that a progressive widening of the pedicle-facet angle might accompany the progressive slip. Remodelling of bone in response to stress and microscopic fatigue fractures might account for such a change.

### TABLE IV

<table>
<thead>
<tr>
<th>Observer . . .</th>
<th>K. H. S.</th>
<th>J. C.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pedicle-facet angle (degrees)</td>
<td>Pedicle-facet angle (degrees)</td>
</tr>
<tr>
<td>Radiographs</td>
<td>Early</td>
<td>Late</td>
</tr>
<tr>
<td>Vertebra</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Third lumbar</td>
<td>122.3</td>
<td>124.8</td>
</tr>
<tr>
<td>Fourth lumbar</td>
<td>118</td>
<td>125.3</td>
</tr>
<tr>
<td>Fifth lumbar</td>
<td>121</td>
<td>123</td>
</tr>
</tbody>
</table>

Two observers measured the pedicle-facet angles in these films (Table IV). One observer (K. H. S.) found that the angle had increased in the third lumbar vertebra by 2.5 degrees, in the fourth by 7.3 degrees and in the fifth by 2 degrees. The other observer (J. C.) recorded increases of 4.8 and 2.3 degrees respectively for the third and fourth lumbar vertebrae and a decrease of 0.7 degree for the fifth.

No definite conclusions can be drawn from these figures obtained from this number of cases.
Summary—One of the possible factors in the etiology of spondylolisthesis with intact neural arch has been investigated. The facet-pedicle angle was measured in seventy-five radiographs of forty-five patients. This angle was found to be no bigger in the slipping vertebra than in the adjacent vertebrae. The evidence regarding change of the pedicle-facet angle with progressive slipping was inconclusive.

Biomechanics—A study of these facts leads to certain conclusions as regards the nature of the pathological mechanism which occurs over a prolonged period. It seems that the essential lesion, namely a pre-spondylolisthetic state, is a soft-tissue instability allowing excessive play at one level. Rissanen (1960) studying the state of the supraspinous and interspinous ligaments in 306 spines of all ages found rupture and degeneration common over the age of thirty. It was notable that all ruptures were confined to the lower three intervertebral spaces and 93 per cent occurred in the lower two.

Allbrook (1957) has shown that the fourth lumbar vertebra has a higher range of mobility than any other lumbar vertebra, the fifth lumbar vertebra being the next most mobile. It seems evident that acquired instability from defect of soft tissues almost invariably occurs at one of the two lower levels. Slipping will only occur, the neural arch being intact, when the facets give way. The facets between the fourth and fifth lumbar vertebrae are more likely to do this because they are placed obliquely to the transverse plane. Those at the lumbo-sacral level are in a coronal (transverse) plane. The soft-tissue instability is prone to give chronic backache and consequently, because of reflex guarding, the spine goes into lordotic spasm, which has the effect of throwing excessive weight upon the neural arches. This combined with the excessive play causes osteoarthritic changes in the zygoapophysial joints, degeneration of the cartilage and grinding in of the facets. This results in a moderate degree of forward slumping of the vertebra. Disc degeneration is commonly observed but the primary soft-tissue lesion is that of the supraspinous and interspinous ligaments.

This study provides further evidence of the importance of the posterior elements to the stability of the lumbar spine. In 197 cases a study was made of the incidence of spina bifida either at the fifth lumbar or the first sacral level. Of 131 cases of spondylolisthesis at the lumbo-sacral level seventy-eight (59·5 per cent) showed spina bifida, while of sixty-six cases of spondylolisthesis at a higher level only four (6·1 per cent) showed spina bifida.

These figures suggest that in a well developed spine an instability is more prone to develop at the higher level, but that in a potentially weak spine the instability develops at the lumbo-sacral level. In other words it can be assumed that spina bifida, which is much more common in the fifth lumbar or first sacral segments, is an etiological factor in the production of instability.

Involvement of nerve tissue—Myelography performed in patients with evidence of involvement of nerve tissue may show either an hour-glass constriction or a complete block to the flow of the radio-opaque material (Figs. 21 and 22). It has been shown (Verbiest 1954) that the
capacity of the spinal canal at the third and fourth lumbar levels is inclined to be diminished and this gives a basis for the explanation of the high incidence of nerve tissue involvement. **Findings at operation**—Exposure of the spinous processes and the neural arches shows a displacement forward of the fourth lumbar spinous process. The neural arch of the slipping vertebra is not loose as in another type of spondylolisthesis. On either side lateral to the lamina is found a mound of osteophytic bone without evidence of the joint line between the two facets. When the dome of this mound has been removed it is seen that the inferior articular facet of the fourth lumbar vertebra has sunk in and become covered over by the osteophytic outgrowths from the superior articular facet of the vertebra below. After removal of the lamina it is often found that the dura is compressed from either side by osteophytic outgrowths from these joints, presenting an hour-glass constriction. These combined with the osteophytic ridge of the back of the superior angle of the body of the fifth lumbar vertebra give a marked constriction of the spinal canal (Fig. 23). Not until a partial facetectomy has been performed are the fifth lumbar roots found. These are seen to be compressed beneath the anterior edge of the superior articular facets.

**DEFICIENCY OF THE NEURAL ARCH**

In theory any loss of continuity of bone between the anterior part of the pedicle and the inferior articular facet will loosen the check on vertebral slipping. A lesion of the pedicle is rare and in this series has only been seen in Groups III and V. The typical lesion, commonly known as spondylolysis, is found in the pars interarticularis and varies from a hairline crack to a clear separation of up to a quarter of an inch or more. The important question which remains controversial is that regarding its origin.

**SPONDYLOLYTIC SPONDYLOLISTHESIS (GROUP II)**

Synonym: True spondylolisthesis.

In this series it was the commonest type and occurred in 164 patients, ninety-three male and seventy-one female. The essential features are the integrity of the anatomical relationship of the facets and an elongation, or more commonly a break, of the pars interarticularis. There is a tendency to regard spondylolysis as a constant feature of spondylolisthesis, in so...
much as the apparent absence of such a lesion in the radiographs is accounted for by poor technique. In studying this group it is easy to assume that spondylolysis is the cause of the slipping, but extensive study of this subject makes it obvious that the explanation is not so simple. Spondylolysis is by no means a constant feature, even within the confines of this group. In young children with the facets in anatomical position, slipping is seen to occur with elongation of the pars interarticularis; in other words there is a sagging of the vertebra from attenuation of bone at the site where stress falls. Figure 24 shows the appearance of a loss of continuity after elongation has occurred.

The nature of spondylolysis

The origin of spondylolysis has given rise to much controversy and evidence accumulating from anatomists, pathologists, radiologists and clinicians has not yet produced sufficient proof to establish its true nature.

Congenital defect—Previously the most generally supported hypothesis was that of a congenital defect; the origin of this defect was thought by many authorities to be due to a lack of fusion between two separate centres of ossification. Gurlt (1864) and Putti (1910) were of the opinion that the lesion was of an atavistic type similar to that seen in reptiles where there is lack of fusion between the body and the pedicle; but this explanation does not ring true since it is well known that the lesion does not occur in the pedicle. Willis (1931) gave a possible explanation after examining serial sections from foetuses. He found that the one centre of ossification developed on two branches of the nutrient artery, and that at first it had the appearance of being separated into two, but that an isthmus was always present although some sections might fail to show it. Friberg (1939) examining sections of eight foetuses found no evidence of two centres but failed to observe the isthmus as described by Willis. He found a continuous bar of bone running through the pars interarticularis where the centre of ossification started to appear. Friberg admitted that his series was small and did not eliminate the possibility of a congenital defect occurring in some cases. An interesting photograph displayed by Friberg (1939) shows lesions of at least five vertebrae from the twelfth thoracic downwards. The significant fact here is that although there is no individual spondylolisthesis of one vertebra on another, there is a universal sagging of the whole lumbar area from marked extension of the pedicles, not from separation at the spondylolysis, indicating the presence of a general bone disease (Group V).

One of the most potent arguments in favour of a congenital lesion is the evidence of heredity. The occurrence of spondylolisthesis in many members of some families seems statistically significant (Friberg 1939, Laurent 1958, Harris 1959). But this is no evidence that spondylolysis itself is of a hereditary nature. If it is argued that spondylolysis is caused by stress it can be argued that undue stress is thrown on this bone as a result of congenital lack of development of the upper part of the sacrum, which is known to be hereditary. Congenital lack of development of the posterior soft tissues or congenital tissue laxity are other possible factors.

Trauma—By trauma is generally meant an injury severe enough to be recalled by the patient when giving his history. It could of course be argued that the patient was either amnesic
or too young at the time to remember the incident or that at the time of the injury there were other major injuries to attract attention, but it has been significant in following the literature of spondylolisthesis that major trauma has not been a constant feature. The force needed to break the pars interarticularis would be very considerable; such a history would certainly be remembered by most patients and the subsequent radiograph would show a fracture of the neural arch. It has been shown experimentally that it is practically impossible to break the pars interarticularis by itself even with great violence. Lane (1893) suggested the idea that the fifth lumbar vertebra could be eroded in extension but review of an anatomical specimen of the vertebral column does not support this idea.

Study of the extensive literature and examination of the findings in this series have persuaded the author to lay aside the hypotheses of congenital defect and acute trauma and to favour that of stress as the most likely causative factor.

Evidence against congenital defect—1) Such a defect has never been found in a foetus or a stillborn; 2) it is frequently seen in young children but the earliest reported is at seventeen months; in other words, it has never been seen before the usual age of walking; 3) the incidence of spondylolysis increases with age. Stewart (1953), studying 786 skeletons which had been brought from Alaska to the Washington National Museum, found that the incidence of spondylolysis increased with age (Table V); 4) slipping is sometimes seen to occur with intact facets before a break appears (Figs. 25 and 26); 5) the break sometimes heals (Figs. 27 to 29). An excellent example of this is shown in Figure 74 of Schmorl and Junghanns (1932); 6) the distance of slip has no relation to the degree of separation of the adjoining edges of the lesion; 7) it would be expected that in a congenital lesion the edges of the gap would be rounded and smooth. They are however ragged and the bone on each side is histologically like that of a pseudarthrosis.

Evidence against acute fracture—1) Great violence is needed to fracture the pars interarticularis; 2) it is almost certain that most of the patients would remember an injury of this severity. A radiograph would show a fracture; 3) fracture of the neural arch caused by a direct blow is rare and does not usually involve the pars interarticularis.
Stress as a cause of spondylolysis—Around the age of one a child starts to walk and during this toddling period the hips, not yet fully extended, cause the lumbar spine to be hyperextended in the erect position (Fig. 30). This must in itself throw an excessive strain on that part of the spine and increase the forward thrust of the lumbar vertebrae. During this period a child is prone to many falls and often tumbles backwards to land hard on the buttocks with the legs stretched out in front. It is not difficult to imagine that any inherent weakness of this area of the spine is liable to be exposed and it is interesting that it is just at this time that spondylolisthesis has first been noted. Many cases have been reported in children around four years old; in this series there are two. The inherent weakness may be one of soft tissues from laxity,
congenital aplasia or acquired damage. It may be one of bone from poor development of the upper sacral facets and of the neural arches of the sacrum, including the median ridge. Any of these factors may expose the last lumbar vertebra to excessive strain. In studying the radiographs of these two early cases no break in the pars interarticularis was seen, but at the age of six one had developed a typical break. Capener (1960) described the case of a little girl with spondylolisthesis and an intact neural arch who developed a secondary spondylolysis when seven years old.

This conception coincides with observations made by Stewart (1953). In examining the incidence of spondylolysis in skeletons from Alaska he found that it was higher in those from the northern coastal districts than in those living inland and to the south. He assumed that the natives living on the coast farther north were more exposed to falls on icy rock and recalled that their work consisted almost entirely of stripping seal blubber which kept them standing with spines fully flexed for long periods. The incidence in these people was as high as 46 per cent. Stewart admitted that at first he was searching for a hereditary factor varying according to race but after an extensive study he considered that the steep increase of the incidence with age made that theory untenable.

The pars interarticularis is the connecting link between the pedicle (and body), the transverse process, the spinous process and lamina and the two articular facets, and, as Roberts (1947) aptly remarks, it is the pivotal centre of the neural arch. The strain on the lumbar vertebrae in an intact spine is considerable but should the rationing process of stress and strain, which is maintained by soft-tissue integrity, break down, an increased stress will fall on one place—the pars interarticularis. Soft-tissue breakdown may be either in the posterior ligaments and muscles or in the intervertebral disc, causing an alteration of the axis of rotation of the vertebra in flexion and extension.
It is rational to suppose that as the spine grows older and passes the osteoid stage to one of fuller mineralisation, the tendency to attenuation becomes less and that to spondylolysis increases. This is in fact reflected in the results of radiographic investigation. **Special observations favouring bone stress**—At an orthopaedic centre on Salisbury Plain during wartime the author had the experience of treating soldiers undergoing strenuous training, involving forced marches with heavy packs. A common cause of backache was a stress fracture of the neural arch. These patients responded well to rest and none was operated on. The radiographic picture was that of an acute stress fracture with the typical periosteal new bone and occasionally a hair-line crack (Fig. 31). It is perhaps disappointing therefore that in the histological examination of specimens taken at operation the classical picture of a stress fracture is not seen, but it can be argued that the patient with an acute stress fracture never comes to operation. Only those patients with persistent pain not responding to conservative treatment are so treated. Under these circumstances the picture has become modified into one of pseudarthrosis under a state of continual traction and it is not surprising that the histological picture is not conclusive. Mosimann (1961) in a recent histological examination of twelve specimens removed at operation comes to the conclusion that the histological picture of spondylolysis in adults is fairly characteristic. He describes the appearance as a synchondro-desmosis, a condition resulting from a preceding pathological process which at present is still not fully explained. One gathers the impression that the writer is inclined to the view that the defect is a pseudarthrosis in type but that he finds insufficient evidence to be definite.

Specimens taken in this series have shown new bone and fibrous tissue and have been reported as showing strong evidence of pseudarthrosis.

**Findings at operation**—At operation the outstanding feature is the looseness of the neural arch from spondylolysis and inadequacy of the posterior ligaments. The degree of slip is not marked. Involvement of nerve tissue is not common, but when present in this series it has been caused by tension of the issuing roots over the posterior aspect of the body of the vertebra below (Fig. 32).

**TRAUMATIC SPONDYLOLISTHESIS (GROUP III)**

There were three cases, all male. In only one case was there definite proof of slipping occurring after an acute fracture of the neural arch. This patient fell backwards landing on his buttocks and at the same time was hit in the lumbar region by a projecting edge of stone.
kerb. A radiograph showed a fracture running from the pars interarticularis into the pedicle. At this time there was no forward displacement of the vertebra. The spine was immobilised in a plaster jacket for three months and during this time the fracture healed, but forward slipping of the fourth on the fifth lumbar vertebra occurred to the extent of one-sixth of the diameter. Both the other patients had a definite history of trauma in which there was a direct blow to the lumbar region. No radiographs were available at the time of injury but later radiographs showed a forward slip and a healed fracture of the neural arch, unlike that of the typical stress fracture.

DEFICIENCY OF BONE STRUCTURE

PATHOLOGICAL SPONDYLOLISTHESIS (GROUP V)

There were six cases, four male and two female. Forward slipping or sagging of one or more vertebrae is caused by insufficiency of bone structure. The bone may be weak from developmental defect as in osteogenesis imperfecta or achondroplasia, from local manifestation of a general disease as in Paget's disease, or from local disease, as in tuberculosis or neoplasm. In this series the causes were osteogenesis imperfecta, achondroplasia, Paget's disease, tuberculosis (two cases) and secondary neoplastic deposit.

These last two groups are rare and do not really enter into the general discussion of the etiology of spondylolisthesis. The cause in each case is self-evident and needs no further explanation, but one point of great interest arises: in general bone disease during the growing period, as in osteogenesis imperfecta, the elongation of bone occurs in the pedicle, whereas in the common type of stress spondylolisthesis the elongation occurs in the pars interarticularis.

SUMMARY

1. During a fifteen-year period a clinical, radiological and in some cases a surgical study has been made of 319 patients suffering from spondylolisthesis—that is, forward slipping of one lumbar vertebra on another or forward sagging of the whole lumbar spine in relation to the sacrum.

2. The five etiological factors are described, and the cases are assigned to five groups according to the factor responsible for the slip. In every case slipping is permitted by a lesion of the apparatus which normally resists the forward thrust of the lower lumbar spine—that is, the hook of the neural arch composed of the pedicle, the pars interarticularis and the inferior articular facet engaging caudally over the superior articular facet of the vertebra below.

3. In Group I (congenital spondylolisthesis—sixty-six cases) the lesion is a congenital defect of the facets. In Group II (spondylolytic spondylolisthesis—164 cases) the lesion occurs in the region of the pars interarticularis and is either an elongation of the bone or a break in continuity. There are reasons for thinking that the lesion is caused by stress over a long period rather than by acute injury or by a congenital anomaly of ossification. In Group IV (degenerative spondylolisthesis—eighty cases) the lesion of the facets is degenerative. There are no good grounds for thinking that an abnormality of the angle between the facets and the pedicles is the primary lesion behind the degenerative change.

4. Group III and V comprise few cases. In the former (traumatic spondylolisthesis—three cases) the lesion—a fracture of the neural arch—is caused by a single severe injury. In Group V (pathological spondylolisthesis—six cases) the slipping is caused by weakness of bone from various causes.

5. A full description is given of the etiological and biomechanical features of each group. A special investigation has been made into the etiological factors in degenerative spondylolisthesis.

6. The incidence of involvement of nerve tissues is highest in degenerative spondylolisthesis; the most severe degrees of slip are found in congenital spondylolisthesis.
THE ETIOLOGY OF SPONDYLOLISTHESIS

In conclusion I wish to express my appreciation to the Consultant Staff of the Royal National Orthopaedic Hospital for permission to examine their patients, to the Staff of the Registry and of the Photographic Departments at the Middlesex Hospital and the Royal National Orthopaedic Hospital for their valuable help, to Miss B. Clayton for her care in preparing the script and to Miss E. Hewland and Mrs I. M. Prentice for preparing illustrations and diagrams.

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VOL. 45 B, NO. 1, FEBRUARY 1963