Pre-clinical Section

VARIATION IN THE HUMAN VERTEBRAL COLUMN, WITH PARTICULAR REFERENCE TO THE LUMBO-SACRAL JUNCTION

L. H. WELLS, *Professor of Anatomy, University of Cape Town*

The developmental variability of the human body is of concern to the anatomist for several different reasons. Like the clinician, he is aware of variations as potential or actual causes of disability which require to be corrected or compensated. At the same time he sees variation, even when it is clinically insignificant, as elucidating normal processes of development. Furthermore, he looks to variation for possible light on the evolution of the distinctive features of human structure.

The human vertebral column is a fertile field for variations, and any anatomy department in time comes to possess a rich collection of vertebrae showing these variations, those related to the lumbo-sacral junction being particularly numerous. This region not only has a complex embryonic history, but as an integral and important part of the anatomy of Man's erect posture it is significant from both the evolutionary and the clinical viewpoint. Indeed it may be said that, judging by its susceptibility to stress injuries, the lumbo-sacral junction is among the most vulnerable points in the mechanism of the erect posture. Consequently, the effect of developmental variations in increasing or decreasing its vulnerability is of particular importance.

DEVELOPMENTAL CONSIDERATIONS

At the stage preceding chondrification[1,2] the vertebro-costal unit is represented by a mesodermal condensation consisting of a *body* encircling the notochord, a dorsal pair of *neural processes* whose extremities are united dorsal to the neural tube by an *interspinal membrane,* and a ventro-lateral pair of *costal processes.* In all except the most caudal units six centres of chondrification appear, two in the body on either side of the notochord, one in each neural process, and one in each costal process.

The cartilage of the neural process ultimately becomes continuous with that of the body. As the neural process chondrifies, it becomes differentiated into pedicle, articular processes, transverse process, and lamina. In the case of a rib-bearing vertebra, the cartilage of the costal element becomes temporarily continuous with that of the body and transverse process; two joint interzones later develop medially and laterally in the plane of junction, separated by an interval occupied by vascular anastomoses. Similar vascular anastomotic areas, but normally no joint interzones, develop in the cervical vertebrae. In the post-thoracic vertebrae, neither joint interzones nor vascular anastomotic areas normally develop between the costal element and the remainder of the vertebra. Except in the most caudal vertebrae, the extremities of the cartilaginous neural processes ultimately unite dorsally, and a spinous process is developed at their junction.

In human embryos between 7 mm. and 11 mm. in length, the precartilaginous sacral vertebrae resemble the lumbar in all essential particulars, although there is a progressive decrease in size from the mid-lumbar region caudally; up to this stage no lines of demarcation can be drawn between the lumbar, sacral, and coccygeal regions. The hipbone rudiment is at first entirely unconnected with the vertebral column, and is situated at the level of the 21st - 23rd vertebrae. It moves later into closer relation with the column, at the same time shifting caudally so that it lies opposite the 25th and 26th vertebrae. The costal processes of these vertebrae are stimulated to more active growth and extend outwards towards the hipbone; this effect normally extends to the 27th, 28th, and 29th vertebrae as well, differentiating the sacrum from the lumbar and coccygeal regions. The enlarged costal elements of these five vertebrae fuse lateral to the ventral branches of the spinal nerves into a continuous mass, and the precartilaginous ilium comes to rest against the cranial and better developed portion of this mass.

While the cartilaginous laminae of the vertebrae are still growing dorsally, centres of ossification appear in the body, in each half of the neural arch, in the free ribs, and in the costal elements of some sacral vertebrae. It may be taken as established that there is a single centre of ossification for the centrum and for each half of the neural arch, but Roche and Rowe[3] have confirmed that very occasionally a separate centre of ossification for an inferior articular process may appear.

VARIATIONS OF LUMBAR AND SACRAL VERTEBRAE

The developmental variations of the lower lumbar and upper sacral vertebrae can be divided into two broad categories. The first comprises those arising from the fundamental pattern of development of the vertebra, the second those directly related to the development of the sacro-iliac articulation.

Variations of Fundamental Pattern

This group may be taken as comprising all types of separation of the primary elements of the vertebra, central, neural, and costal, as well as partial suppression of any of these elements.

Fig. 1A illustrates the demarcation of the central, costal, and neural components in an infantile first sacral vertebra. A foramen is occasionally found piercing the lateral mass of this vertebra, and is interpreted as being due to an

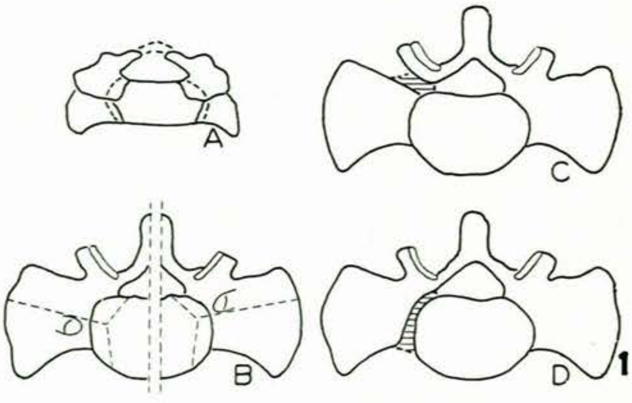


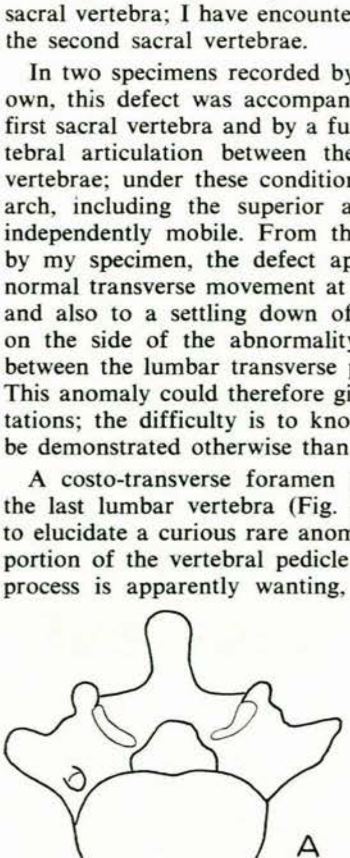
Fig. 1. A. Infantile first sacral vertebra showing extent of component ossifications. B. Costo-transverse foramina in first sacral vertebra, showing displacement ventrally and dorsally from original line of costo-transverse junction. C. Defect of pedicle between transverse and superior articular processes. D. Defect of neuro-costo-central junction.

abnormal vascular anastomosis in the costo-transverse junction; Fig. 1B illustrates two examples of such a foramen, both of which appear in the course of growth to have been somewhat displaced from the original line of junction.

Failure of bony union at the neuro-costo-central synchondrosis (Fig. 1D) is clearly a very rare anomaly; I have met with one example in the first sacral vertebra, and one in the second sacral vertebra is depicted by Grant.[4] Also rare, but possibly of greater practical importance, is an interruption of the pedicle between the transverse and superior articular processes (Fig. 1C). This anomaly was first clearly described by Rowe[5] in the first sacral vertebra; I have encountered it in both the first and the second sacral vertebrae.

In two specimens recorded by Rowe, and in one of my own, this defect was accompanied by spina bifida in the first sacral vertebra and by a functional posterior intervertebral articulation between the first and second sacral vertebrae; under these conditions a portion of the neural arch, including the superior articular process, becomes independently mobile. From the reactive changes shown by my specimen, the defect appears to have led to abnormal transverse movement at the lumbo-sacral junction, and also to a settling down of the last lumbar vertebra on the side of the abnormality, compressing the tissues between the lumbar transverse process and the sacral ala. This anomaly could therefore give rise to clinical manifestations; the difficulty is to know how its existence could be demonstrated otherwise than at operation.

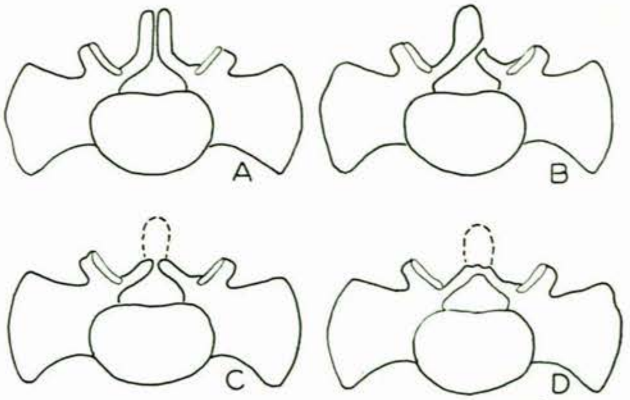
A costo-transverse foramen is occasionally present in the last lumbar vertebra (Fig. 2A). Such specimens help to elucidate a curious rare anomaly (Fig. 2B) in which the portion of the vertebral pedicle anterior to the transverse process is apparently wanting, the body and transverse process being connected only by the costal element. It is not necessary to infer a separate centre of ossification for the costal element in such cases; it could well become ossified by extension from the body and transverse process as normally occurs in cervical vertebrae.



2

Fig. 2. A. Costo-transverse foramen in last lumbar vertebra. B. Defect of pedicle ventral to transverse process.

Fig. 3 illustrates the various types of mid-dorsal defect which are encountered. The spinous process may be cloven in two (Fig. 3A) or separated from one lamina by a paramedian defect (Fig 3B), i.e. both of the ununited neural processes, or one only, may give rise to a spinous element. Spina bifida occulta, with complete absence of the spinous process (Fig. 3C) represents a more severe degree of defect, leading to clinical spina bifida. Alternatively, the two laminae may unite normally in the midline, but no spinous process is developed (Fig. 3D).



3

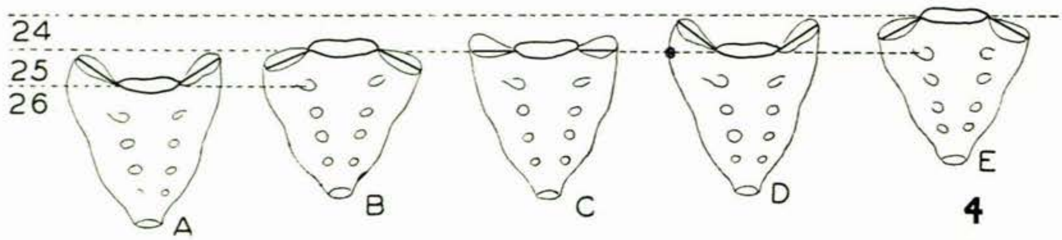
Fig. 3. A. Spina bifida with spinous processes developed from both laminae. B. Spina bifida with spinous process developed from one lamina only. C. Spina bifida with suppression of spinous process. D. Suppression of spinous process without spina bifida.

Although the conditions described present themselves as bony defects, it appears that in practically every case their existence was determined before ossification. Either a normal cartilage model was not laid down, which appears to be usually the case in spina bifida, or part of the cartilage model subsequently suffered degenerative changes which prevented it from becoming ossified; the latter explanation appears preferable for suppression of part of the pedicle, and probably also for defect at the neuro-costo-central junction.

Variations Related to the Sacro-iliac Articulation

The variations resulting from the development of the sacro-iliac articulation can be divided into three groups: (1) variation in the level of the most cranial vertebra taking effective part in the sacro-iliac joint (fulcral vertebra); (2) assimilation of the vertebra cranial to the fulcral vertebra to the sacrum; and (3) variation in the relation of the last free lumbar vertebra to the iliac crest.

1. *Variation of the fulcral vertebra.* The hipbone in its migration may come to rest against the vertebral column either more cranially or more caudally than usual, so that the fulcral vertebra is either the 24th or the 26th (Fig. 4). This figure also illustrates another mechanism by which variation in the level of sacro-iliac contact may be taken up; the upper surface of the body of the fulcral vertebra may come to lie either cranial to, level with, or caudal to the cranial margin of the sacro-iliac articulation, giving rise to the three forms of sacrum which Radlauer[6] designated hyperbasal, homobasal, and hypobasal. It appears, understandably, that sacra in which the fulcral vertebra is the 24th are almost invariably hypobasal, and those in which it is the 26th are most commonly hyperbasal. Where the sacrum is hyperbasal in form, loss of substance in the lumbo-sacral intervertebral disc is particularly likely to bring the transverse processes of the last lumbar verte-



4

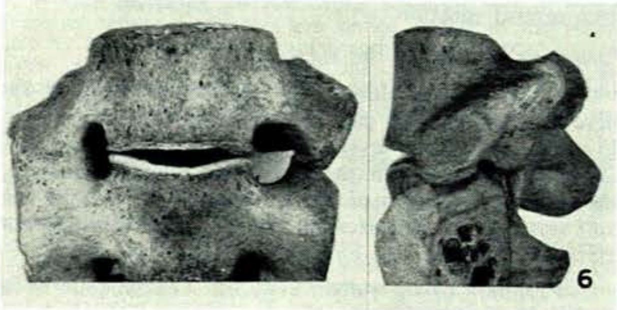
Fig. 4. Variation in fulcral level of sacrum and in form of sacral base (modified from Radlauer[6]). A and D hyperbasal; B and E, hypobasal; C, homobasal.

bra into contact with the sacral alae, causing compression of the intervening structures and possibly forming a false joint.

5

Fig. 5. Last lumbar vertebra and upper part of sacrum from column in which the fulcral vertebra is the 26th (University of Cape Town collection).

In the specimen illustrated in Fig. 5, the fulcral vertebra is the 26th, the 25th presenting the characters of a normal last lumbar vertebra; this condition may correctly be described as lumbarization of the 25th vertebra. Fig. 6 shows a specimen in which the fulcral vertebra is the 24th; this may be termed sacralization of the 24th vertebra. The unossified synchondrosis between the left lateral masses of the 24th and 25th vertebrae in this specimen, owing to immaturity, affords an instructive comparison with some examples in the following group of variations.



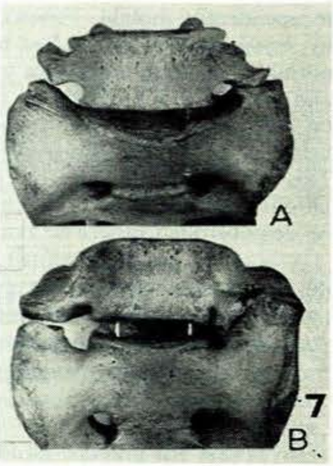
6

Fig. 6. Upper part of immature sacrum in which the fulcral vertebra is the 24th; ventral and lateral aspects (UCT collection).

Willis[7] found 9 instances in 850 vertebral columns in which the first sacral (fulcral) vertebra was definitely the 24th, against 33 in which it was the 26th.

2. *Variation of the pre-fulcral vertebra.* The costal element of the pre-fulcral vertebra may react to the proximity of the hipbone by becoming enlarged and more or less differentiated from the transverse process, even if a separate centre of ossification does not develop in it. These variations show a continuous sequence from a last lumbar costo-transverse process just perceptibly differentiated into costal and transverse components, to a greatly expanded costal element either fused or articulated with the ala of the fulcral vertebra. This condition is frequently termed either 'sacralization of the last lumbar vertebra' or 'lumbarization of the first sacral vertebra'; I prefer to describe it as assimilation of the pre-fulcral vertebra to the sacrum.

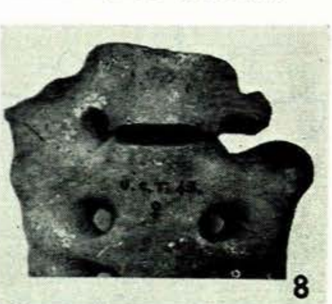
An enlarged costal element which is initially free from the ala may impinge on it, like a normal last lumbar costo-transverse process, through loss of substance in the intervertebral disc; the example shown in Fig. 7A may belong to this type. The enlarged costal element may, however, be developmentally incorporated into the lateral mass of the sacrum, so that at birth it is united to the ala of the fulcral vertebra by a synchondrosis, although it takes no effective part in forming the sacro-iliac articular surface. In some of these cases the synchondrosis later becomes more or less completely co-ossified; in others, however, probably as a result of postural strains, it becomes mobilized, forming a pseudoarthrosis. These lateral lumbo-sacral pseudoarthroses sometimes develop massive osteophytic outgrowths around their margins, which may seriously encroach on the space for the nerves emerging between the pre-fulcral and fulcral vertebrae (Fig. 7B).



7

Fig. 7. A. Enlarged costal element of last lumbar vertebra articulating with lateral mass of sacrum (UCT collection). B. Bilateral assimilation of last lumbar vertebra to sacrum, with secondary mobilization of lateral lumbo-sacral synchondrosis; massive osteophytes on left side encroaching on space for anterior division of nerve (UCT collection).

When the pre-fulcral vertebra is completely co-ossified with the sacrum, it may be extremely difficult to determine whether it enters into the sacro-iliac articular

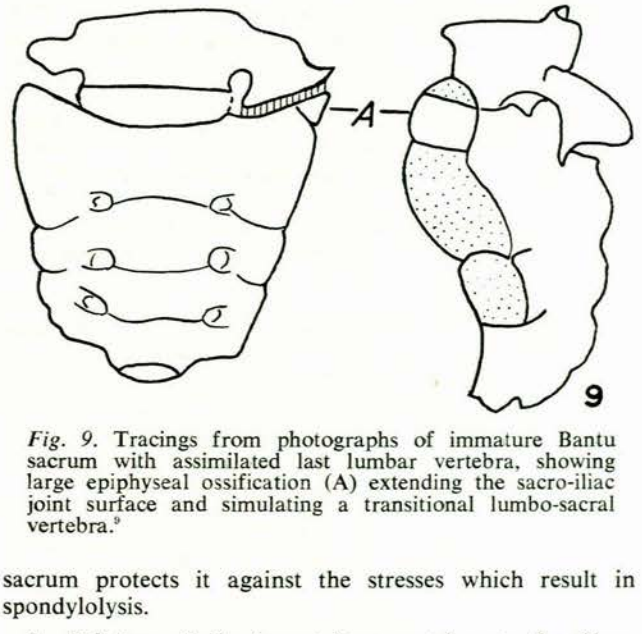


8

Fig. 8. So-called transitional lumbo-sacral vertebra (Bushwoman, UCT collection).

surface or not. In this category fall specimens, such as Fig. 8, in which a vertebra appears to form part of the sacro-iliac surface on one side but not on the other; this is sometimes described as a transitional lumbo-sacral vertebra.[4] However, Fawcett[8] and Shore[9] have described immature specimens in which the apparent extension of the articular surface on to the 'transitional' vertebra is seen to be carried by a large wedge-shaped epiphyseal ossification related to the upper border of the vertebra below, which is the true fulcral vertebra (Fig. 9); it appears probable that most cases of an apparent transitional vertebra are to be accounted for in this way, and that instances in which the fulcral level differs on the two sides are in fact extremely rare. The relation of this epiphysis to the normal pattern of secondary ossification over the sacro-iliac joint surface is not clear, largely because specimens in the relevant age-group are rarely obtainable for study.

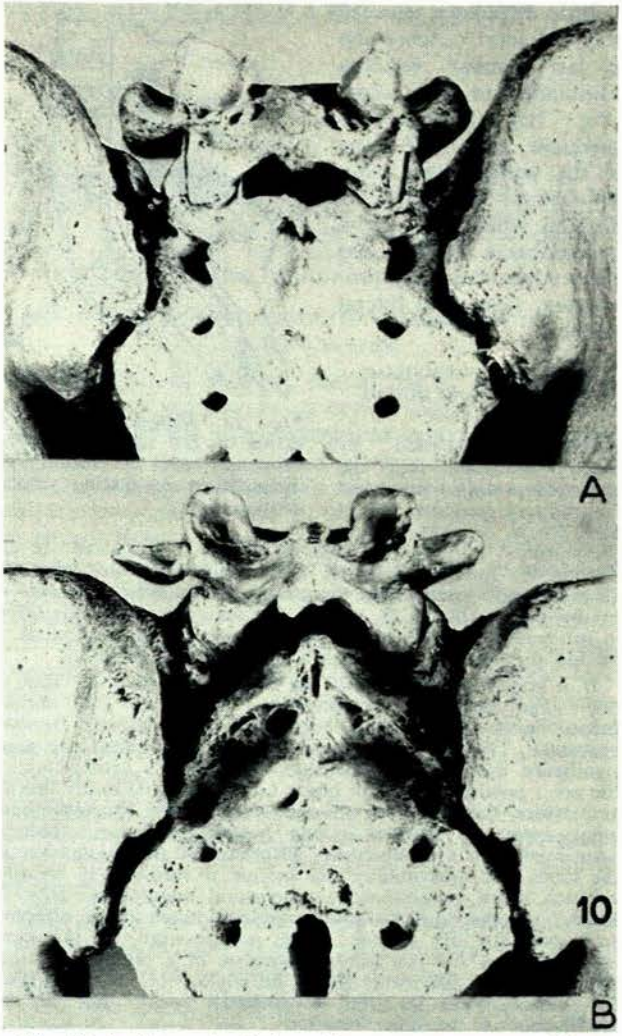
Willis,[7] in his series of 850 vertebral columns, encountered 38 instances in which the 24th vertebra was 'partially fused or articulated with the sacrum', and 18 in which the 25th was 'partially freed from the sacrum'. Although his criteria may not be identical with those adopted in this study, it appears safe to infer that most of the former group, and at least some of the latter, are cases of assimilation of the pre-fulcral vertebra to the sacrum. Lanier,[10] in 200 vertebral columns, observed 14 instances of 'sacralization' of the last lumbar transverse process, 4 being unilateral and the remainder bilateral. In contrast to these figures, Roche and Rowe,[11] in 171 cases of spondylolysis, found only 3 in which an enlarged transverse process of the last lumbar vertebra articulated with the sacrum or ilium or both. These figures suggest that assimilation of the last lumbar vertebra to the sacrum protects it against the stresses which result in spondylolysis.



9

Fig. 9. Tracings from photographs of immature Bantu sacrum with assimilated last lumbar vertebra, showing large epiphyseal ossification (A) extending the sacro-iliac joint surface and simulating a transitional lumbo-sacral vertebra.[9]

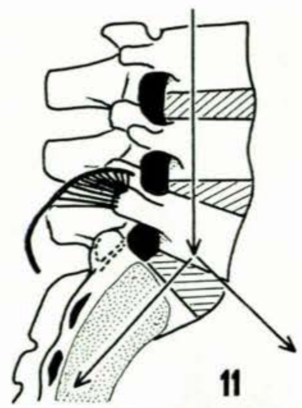
3. *Relation of the lowest free vertebra to the ilium.* Normally the costo-transverse process of the last free lumbar vertebra lies caudal to the iliac crest (Fig. 10A) and its extremity is connected to the medial surface of the ilium by the powerful ilio-lumbar ligament. If the sacrum is hypobasal in form, however, this process may lie on a level with the iliac crest or even cranial to it (Fig. 10B). In these cases the process is much slighter than usual, resembling that of the normal fourth lumbar vertebra, and its ligamentous connection with the ilium is equally slight, the morphological 'ilio-lumbar' ligament being attached to the transverse element of the first sacral ala.



10

Fig. 10. A. Normal relation of transverse process of last lumbar vertebra to ilium; sacrum homobasal (UCT collection). B. Transverse process of last lumbar vertebra cranial to iliac crest; sacrum hypobasal (UCT collection).

Davis[12] has recently emphasized the importance of the ilio-lumbar ligament in resisting the forces which tend to displace the last lumbar vertebra over the promontory of the sacrum (Fig. 11). A weak connection of the last lumbar vertebra with the ilium might therefore be expected to make the lumbo-sacral junction in these cases unusually susceptible to stress. Some hypobasal sacra, however, present a secondary promontory between the first and second pieces, so that the fulcral vertebra in effect possesses the normal relations of the last lumbar vertebra (Fig. 6); except in its relation to the sacro-iliac joint, there is little difference between such a fulcral vertebra and a last lumbar vertebra assimilated to the sacrum (Fig. 7B). Theoretically, therefore, effects of stress at the lumbo-sacral junction appear most likely to develop when the sacrum is hypobasal in form and there is no secondary promontory below the fulcral vertebra.



11

Fig. 11. Diagram of forces acting on last lumbar vertebra, showing role of ilio-lumbar ligament in preventing ventral displacement.[12]

THE LUMBO-SACRO-ILIAC MECHANISM AND HUMAN PHYLOGENY

Evidence marshalled by Todd[13] indicated that the ancestral primates possessed 26 pre-sacral vertebrae. Most Old World monkeys retain this number, although in some individuals it is reduced to 25. Among the man-like apes, in the gibbons there are normally 25 pre-sacral vertebrae, in the chimpanzee most commonly 24, in the gorilla 24 or 23, and in the orangutan usually 23; it is inferred[14] that the diminished number in these animals is related to their specialization for quasi-erect climbing.

If it can be inferred that the earlier ancestors of Man at one stage possessed 26 pre-sacral vertebrae, the normal fulcral level in Man has been displaced cranially by two vertebrae. This however is not the only or indeed the most significant modification associated with Man's assumption of the erect posture. The iliac blade in Man is very much shorter and wider than that in monkeys and apes, the difference being especially evident in the posterior portion.[15] This is associated with a conspicuous difference in the orientation of the sacro-iliac articulation; the sacrum is retroverted, creating a much more pronounced lumbo-sacral angulation. This, as Keith[16] pointed out, makes available a much more effective anchorage for the erector spinae muscle mass; at the same time, it places the last lumbar vertebra in a precarious situation relative to the forces acting on it (Fig. 11), and so makes the lumbo-sacral junction a potential weak link in the mechanism of the erect posture.

The fossil evidence at present available throws very little light on the evolution of the characteristic features of the human lumbo-sacro-iliac mechanism. Strauss and Cave[17] have demonstrated that, contrary to the traditional assertion, the vertebral column and hipbone of the Neanderthal group of human fossils afford no evidence of an incompletely erect posture, and do not differ in any significant feature from those of existing Man; there are no data bearing on lumbo-sacral variation in this group. In the present state of our knowledge there appears no reason to suppose that any known human types were other than fully erect or that their lumbo-sacro-iliac complex would have differed appreciably from that of modern Man.

Cumulative evidence, summarized by Robinson,[18] has established that the fossil Australopithecines were erect bipeds in which the form of the iliac blade and the orientation of the sacro-iliac joint were essentially similar to those of Man. Only one incomplete vertebral column of this group is as yet available for study. According to Robinson (personal communication) this possesses six lumbar vertebrae, the most caudal having a partially differentiated costal process which does not, however, articulate with the sacral ala. The sacrum is incomplete, but it is clear that only two sacral vertebrae articulated with the ilium; all the known Australopithecine ilia suggest that only two vertebrae, and not three as is usual in Man, were involved in this articulation. The number of thoracic vertebrae cannot be established; it cannot therefore be concluded that the total number of pre-sacral vertebrae was necessarily 25, still less that this was the usual number in this group. So far as the postural mechanisms are concerned, the gap between the Australopithecines and Man is vastly less than that between the Australopithecines and any other known primates.

The structural specializations of the human foot[19] show that the ancestors of Man were at one time specialized for an ape-like climbing habit, which they later abandoned for terrestrial bipedalism. Robinson[18] pointed out that the humanoid characteristics of the hipbone and lumbo-sacro-iliac complex must have been developed either together with or before this change of habit. Where the inferred change in the fulcral level would have taken place in relation to this development cannot be deduced from the available evidence.

The migration of the early embryonic hipbone, demonstrated by Bardeen,[2] provides the mechanism for an evolutionary change in the fulcral level. In this process the human hipbone now moves caudally by two or three segments; before inferring that the pre-sacral column of Man was shortened by limiting the extent of this movement, it would be necessary to demonstrate that in lower primates the caudal migration of the hipbone is greater.

If it is inferred that the fulcral level in Man has been displaced cranially, the increase to 25 pre-sacral vertebrae can be described as a reversionary variation; it is not however justifiable to label the decrease to 23 pre-sacral vertebrae progressive, as though implying that it foreshadows a future trend in human evolution. Such data as those of Willis suggest that cranial displacement of the fulcral level has reached its limit. Keith[14] indeed suggested that terrestrial bipedalism might favour a tendency again to displace the fulcral level caudally, increasing the number of pre-sacral vertebrae to 25. Although Willis's data may suggest that the tendency to caudal displacement outweighs that to cranial displacement, Todd[13] was probably more justified in stressing the high degree of stability which the fulcral level in Man has attained. Roche and Rowe's[11] observations, however, suggest the possibility that assimilation of the last lumbar vertebra to the sacrum might prove in the long term most advantageous for the stability of the lumbo-sacral junction.

Forty years ago, Keith[16] summed up his reflections on the evolution and disorders of the human vertebral column as follows: 'It is not true . . . to say that our spines are not perfectly adapted to the upright posture; it would be more accurate to say that human spines were not evolved to withstand the monotonous and trying postures entailed by modern education and by many modern industries'. If in the intervening years some progress has been made in eliminating the causes of functional strain of which Keith was most aware, the conditions of life continue to create others. As with all adaptive processes, Man's capacity to adjust his lumbo-sacro-iliac mechanism to the demands on it depends on the persistence of a tendency to variation, but this is a double-edged weapon equally capable of producing disability.

I wish to thank Dr. A. G. Ramsay, Department of Physiology, for the photographs, and Mr. D. J. Coetzee, Department of Anatomy, for the line drawings.

REFERENCES

1. Bardeen, C. R. (1905): Amer. J. Anat., **4,** 163.
2. *Idem* (1905): *Ibid.*, **4,** 265.
3. Roche, M. B. and Rowe, G. G. (1951): Anat. Rec., **109,** 253.
4. Grant, J. C. B. (1956): *Atlas of Anatomy*, 4th ed., figs. 357 and 358. London: Baillière, Tindall and Cox, Ltd.
5. Rowe, G. G. (1950). Anat. Rec., **107,** 171.
6. Radlauer, C. (1908): Morph. Jb., **38,** 323.
7. Willis, T. A. (1923): Anat. Rec., **26,** 31.
8. Fawcett, E. (1907): Anat. Anz., **30,** 414.
9. Shore, L. R. (1930): J. Anat., **64,** 206.
10. Lanier, R. R. (1939): Amer. J. Phys. Anthrop., **25,** 341.
11. Roche, M. B. and Rowe, G. G. (1951): Anat. Rec., **109,** 233.
12. Davis, P. R. (1961): J. Anat., **95,** 337.
13. Todd, T. W. (1923): Anat. Rec., **24,** 261.
14. Keith, A. (1903): J. Anat., **37,** 18.
15. Strauss, W. L. (1929): Amer. J. Anat., **43,** 403.
16. Keith, A. (1923): Brit. Med. J., **1,** 499.
17. Strauss, W. L. and Cave, A. J. E. (1957): Quart. Rev. Biol., **32,** 348.
18. Robinson, J. T. *in* Kurth, G. ed. (1962): *Evolution und Hominisation*, pp. 120 - 140. Stuttgart: G. Fischer
19. Wells, L. H. (1931): Amer. J. Phys. Anthrop., **25,** 185.