ANATOMICAL ASPECTS OF SOME VERTEBRAL ANOMALIES

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During a course of study in the Anatomy Department of the University of Cape Town under Professor Wells, specimens of vertebral anomalies were worked on and I thought they would be of interest to physiotherapists as some of them must undoubtedly have given rise to symptoms of backache.

As the causation of some of these conditions are developmental a little background embryology is necessary to discussing the anomalies themselves.

EMBRYOLOGY

After differentiation of the cells of the embryo into the three layers of ectoderm, mesoderm and entoderm, and the formation of the neural tube for the spinal cord with the notochord (a structure running the length of the embryo) lying beneath it, a condensation of mesodermal cells comes to lie beneath and lateral to the neural tube. These cells migrate around the tube to form the first template, as it were, of the neural arch. Cells below the tube move medially and condense to form the pattern of the vertebral body, enclosing the notochord. Longitudinally this mass is marked off into segments of dense and less dense cell masses.

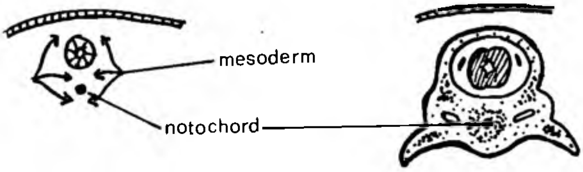

Fig. 1. Diagramatic cross-section embryo showing migrating mesoderm.

When the embryo is about five weeks old, these primitive mesenchymal cells, as they are now called, start to form cartilage. There is a pattern of chondrification which is closely allied to that of later ossification, with centres appearing in the body, one on either side of the neural arch and one for the lateral costal process on each side making five centres in all for each vertebra.

Once the mesenchymal model has all been converted to cartilage the process of ossification commences with invasion of the cartilage by blood vessels, the dying off of the cartilage and its replacement by bone. As stated before, the centres of ossification correspond to those of chondrification i.e. one for the body, two for each neural arch in the cervical and lumbar region and an additional two for the costal elements only in the thoracic region, C7 and sacral region. The ossification of the atlas and axis vertebrae are not discussed here.

In the thoracic region these costal elements ultimately form the ribs. In the sacrum they unite first to the transverse processes then the two unite to the body of the vertebra and finally they fuse longitudinally to form the lateral mass of the sacrum. Much controversy surrounds the ossification centres of the costal elements, some authors stating that they occur in all vertebrae, and that the anterior part of the lateral process of the cervical vertebra has a separate centre of ossification corresponding to the costal process in the thoracic region. The anatomical terminology for this part of the process is the costal element and seems to have derived either from an early concept of separate centres as stated above or because it corresponds to the same process in some reptiles. To add to the confusion, in the lumbar region the costal element is said to have fused to the transverse process to form the lateral process, but how much is costal process and how much transverse process is another matter for keen debate. General concensus of opinion would seem to favour ossification centres for costal elements for thoracic, lower cervical, sacral and perhaps L5, while for descriptive purposes there remains an area by this name for each vertebra.

The centres for the bodies appear first and then those for the neural arches and costal elements. By birth all centres of ossification are present and well established, with a layer of cartilage separating neural arch in the midline posteriorly, and neural arch from body on either side anteriorly. The transverse processes grow out from the neural arch as do the articular processes.

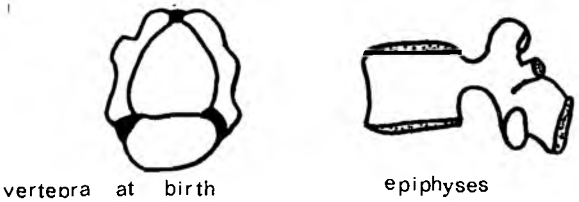

Fig. 2. Diagram of vertebra at birth and epiphyses at puberty.

Fusion, i.e. complete bony bridging of the neural arches occurs progressively up to three years of age and fusion of the neural arches to the body occurs between 3 and 7 years. At puberty secondary ossification centres appear on the tips of the spinous processes, the transverse processes and on the inferior and superior surfaces of the body—here in the form of a peripheral ring of ossification. These secondary centres fuse to the main part of each vertebra at about 25 years of age. The sacrum is a little more involved with longitudinal fusing of costal elements to form the lateral mass and a merging of secondary centres to form the auricular epiphyseal plate for the sacro-iliac joint and the tubercles. The bodies also fuse from below upwards to form the mass of the sacrum.

SEGMENTATION AND FORMATION OF INTERVERTEBRAL DISC

Longitudinally the original mesoderm mass shows successive areas of dense and less dense cells, giving a segmental pattern. A division occurs in the dense areas and they form cranial and caudal halves. Each vertebral body is made up of a cranial and a caudal part of two segments. The dense areas left become the intervertebral disc.

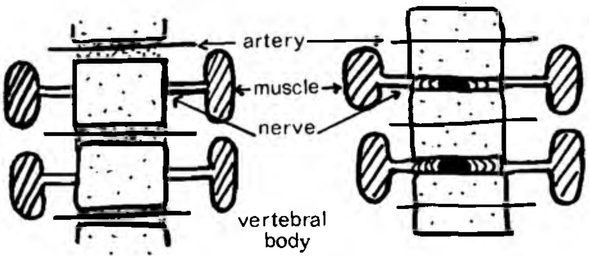

Fig. 3. Diagram of formation of vertebral body from original mesoderm segments.

It will be remembered that the cells forming the body surrounded the notochord and this structure regresses, remaining only in the centre of the intervertebral disc as the nucleus pulposus. This nucleus is at first a mucoid substance which is gradually replaced by fibro-cartilage, remaining semi-fluid in the young and thus freely adaptive to movement. In the middle-aged and elderly more replacement by fibro-cartilage renders it less adaptable and more susceptible to degeneration.

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The conversion of the mesenchymal cells surrounding the nucleus to fibro-cartilage forms the annulus fibrosus. Of interest is the fact that the nucleus pulposus lies more posteriorly than centrally, due to growth of the vertebral body anteriorly with the posterior part of the annulus therefore thin and weaker than the anterior part. Also, with the development of the cervical and lumbar curves, the disc becomes compressed posteriorly, further weakening the annulus as unsupported fibrous tissues, i.e. not in a bony matrix can withstand tensile force but not compression. These two factors predispose to injury and degeneration of the fibres of the annulus in this region.

The Ilium

With its three centres of ossification, this bone is formed from a condensation of mesenchyme. The superior part lies opposite vertebral segments 21–23, and moves down to lie opposite segment 25, making this vertebra the most usual sacral I, with 24 pre-sacral vertebrae formed by the well-known regions into seven cervical, twelve thoracic and five lumbar.

LIGAMENTS

These are well known, being divisible into:

(a) **Longitudinal group**—anterior and posterior on bodies, attached to the intervertebral discs, and the supraspinous ligament attached along the tips of the spinous processes.

(b) **Intervertebral group**—the ligamentum flavum uniting lamina to lamina anteriorly and being highly elastic is the most important of these. The spines and transverse processes are also united by interspinous and intertransverse ligaments, leaving only pedicles un-united to allow the passage of spinal nerves.

(c) **Articular capsules**—surrounding the joints of the vertebral arches.

(d) **Lumbo-sacral region**—the additional anterior, posterior and interosseous sacro-iliac ligaments stabilise the area. The tendency of L5 to be displaced forward on the sacrum due to the weight of the body and the backward angulation of the sacrum at this point is counteracted by the strong ilio-lumbar ligament running from the transverse processes of L5, to the iliac crest.

MUSCLES

These are numerous and rather complicated in their arrangement. They appear to form a deep group of small muscles more or less from vertebra to vertebra; an intermediate group of longer muscles bridging 4–6 vertebra and a superficial group forming long columns successively up the back. From a functional point of view, the deep muscles would be fitted more for balance adjustment vertebra on vertebra, with the superficial group responsible for grosser movements of the trunk. The intermediate group could assist in both functions. The names and arrangements of these muscles can be found in any recognised textbook of anatomy.

Of interest is recent work by Professor Trevor Jones showing a wedge of muscle, made up of successive laminae uniting the spinous and transverse processes of the lumbar spine individually to the sacrum and iliac crest. This arrangement further supports the vulnerable lumbo-sacral and sacro-iliac region.

BONY ABNORMALITIES

This term refers here to some developmental anomalies and functional conditions and not to gross pathological deformities.

Levels of Incidence

It would appear that where the character of the vertebra is changing from one form to another, the likelihood of abnormality is greatest. Sacral I is the vertebra with the highest incidence of abnormality with the other regional junctions of C1, C7 and T1, T12 and L1 following with varying degrees of incidence.

DEVELOPMENTAL ANOMALIES

Spina Bifida

Non-union of the neural arch posteriorly accounts for this condition. The cleft is usually through the middle of the process, the two sides being symmetrical. If the cleft is paramedian, the preponderence of bone tends to be on the right side. The incidence of this condition is said to be in the region of 1,2% which although not high, is higher than most of the other conditions. This slight bony defect is of no great clinical significance but must weaken ligamentous support, particularly in the lumbo-sacral region. Where there is gross separation of the arches and herniation of the cord and meninges, meningomyelocoel results with all its complications and problems. It is thought to be lack of initial chondrification and therefore no final ossification.

Fig. 4. Drawing from specimens of spina bifida.

Absence of Spinous Process

This may be associated with the above condition or the neural arch may have fused but no spinous process formed. Once again ligamentous and muscular support is weakened.

Cervical and Lumbar ribs

C7 and L1 occasionally have costal elements actually forming a small rib which may be completely separated from the vertebra by synovial joints or partly or completely fused to it. In the cervical region symptoms arise from stretching of the brachial plexus over this rib with perhaps vascular symptoms as well from stretching of the subclavian artery.

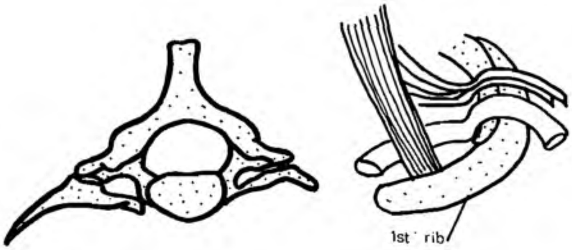

Fig. 5. Drawing from specimen of cervical rib and diagramatic representation of kinking of subclavian artery and brachial plexus by the rib.

Wedged and Hemivertebrae

Although not common these two conditions lead to either a kyphosis or scoliosis. Wedging of the anterior body of the vertebra is the cause of the former and failure of one half of the body to develop causes the latter. This defect appears to be an early fault in the laying down of the mesodermal model.

Foramina

A foramen may be present in the lateral mass of S1 or in L5 which appears to be rather akin to the transverse foramen for the vertebral artery in the cervical region. This is formed by a vascular anastomosis in the cartilage model causing rarefraction. Various abnormalities occur in the lateral process of the cervical vertebra with failure to form the complete foramen either anteriorly or posteriorly, or with narrowing of the foramen. This could cause vascular symptoms affecting the vertebral artery.

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Absent Anterior Arch of the Atlas

In one specimen complete failure of the anterior arch of the Atlas was seen. The specimen was of a five-year-old child and it is possible that there was hypermobility in the area. There also appears to be failure of the posterior arch to unite and a defect in the costal elements forming the transverse foramen anteriorly. The failure of the bone elements to fuse to form the complete bone is thought to be due to the normal cartilage model not being laid down originally in the mesodermal mass or that an area of cartilage degenerates before ossification could occur.

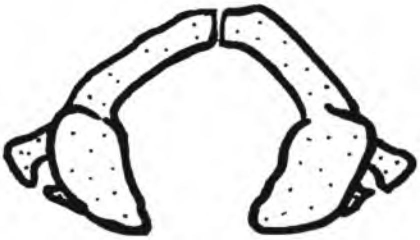

Fig. 6. Drawing from specimen of absence of anterior arch of atlas.

Lumbo-sacral Abnormalities

With the normal strain imposed on this area in weight-bearing in the erect position, any abnormality which may further weaken the area is likely to cause strain on ligaments and soft tissues and to cause reactive bony outgrowths all of which could contribute to symptoms of backache.

Level of the Fulcral Vertebra and Assimilation of the last Pre-sacral Vertebra

The normal numbering of vertebrae makes T1 the 8th Vertebra, L1 the 20th and S1 the 25th. There are thus twenty-four pre-sacral vertebrae with the 25th being the most cranial articulating with the ilium and known as the fulcral vertebra. This term is not to be confused with S2 when referring to the axis of the sacro-iliac joint. However this pattern is not always adhered to in development. With the descent of the ilium and subsequent segmentation of the mesenchymal condensation forming the vertebral column the fulcral vertebra may be the 24th or 26th, the ilium in these cases having moved down a further segment or not descended far enough as the case may be.

If the 24th vertebra is the fulcral vertebra there will only be four lumbar vertebra and the sacral will have six segments. this upper segment may be completely fused to the sacrum or it may be partly fused by the lateral masses with the neural arch still separate. It may participate in the sacro-iliac joint or the auricular surface may still extend only as far as the 25th vertebra. If incompletely incorporated in the sacro-iliac joint there is a tendency for the lateral mass to become secondarily mobilised. Where the fulcral vertebra is the 26th the first coccygeal segment is often fused to the sacrum at the base giving a five piece sacrum rather than a four piece which is rarely seen. Sometimes a transitional vertebra is seen with the last presacral vertebra completely fused on one side to the sacrum and exhibiting completely normal lumbar 5 on the other side.

In development, lack of segmentation of L5 from S1 lateral mass in the primitive mesenchyme may result in a similar abnormality to some of the above. The cartilage laid down follows the mesenchymal pattern with L5 having unusually large downward lateral processes continuous with the costal elements forming the lateral mass of the sacrum. Since ossification proceeds more slowly and the area is already under strain from post-natal use, the cartilage at this point of junction breaks down before becoming ossified and an articulation is formed between the lateral processes of L5 and that of S1. With continued use the strain on this articulation may cause reactive bony proliferation and in the specimen illustrated on the right encroachment of the anterior intervertebral foramen is likely to have caused pressure on L5 nerve root. The specimen on the left illustrates complete spina bifida in the sacrum as well.

Plate 1. Specimen of 4-piece sacrum with spina bifida and last presacral vertebral showing enlarged lateral processes with secondary joint formation with lateral mass of sacrum on the left.

Several other factors may predispose to this articulation of L5 on S1 lateral mass. Variations in the L5 lateral processes can be seen from the diagram with the lower more anterior costal element becoming larger and projecting more inferiorly thus increasing the likelihood of it meeting the sacral lateral mass.

Added to this is a factor introduced by the angle formed between the body of the sacrum and its lateral mass. If the lateral masses incline upwards in relation to the body—the sacrum is said to be hyperbasal—the possibility of an articulation with L5 increases. If the masses are horizontal—homobasal—or slope downwards—hypobasal—the possibility is

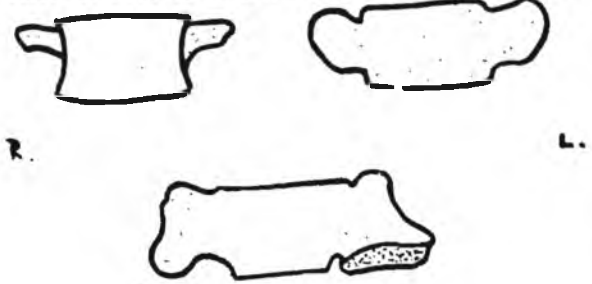

Fig. 7. Drawings from specimens of lumbar 5 vertebrae showing differences in lateral processes.

Plate 2. Specimen of 5-piece sacrum, secondary mobilisation of lateral mass with last presacral vertebra and bony proliferation encroaching on anterior intervertebral foramen on left.

Fig. 8. Diagram showing hyperbasal, homobasal and hypobasal sacra.

less. This different slope is thought to be partly associated with the ilium and the final position it adopts in its descent.

Still a further factor in the formation of this abnormality is functional where a scoliosis with increased weight and approximation on one side may ultimately cause a secondary articulation. Similarly degeneration of the L5 intervertebral disc may cause this vertebra to settle on the lateral mass of the sacrum if its own lateral masses are already large and downward projecting.

Spondylolysis and Spondylolisthesis

Much confusion always seems to exist in students' minds over these two conditions. The former refers to a defect in the lamina of the neural arch between the articular processes. The latter refers to the slipping forward of a vertebra on the one below with or without a spondylolysis being present.

The mechanics of the lumbosacral junction where this condition is most common, are well known to the physiotherapist. The transference of the weight of the trunk borne on L5 to the backwardly angled sacrum is a hazardous procedure. The spinal ligaments play their part in stabilising the area but require help from the ilio-lumbar ligament holding L5 lateral process to the iliac crest. This ligament may be weakened due to a hypobasal sacrum lengthening its course or a small process on L5 affording too little room for attachment for a ligament of any strength. Continued usage of the area causes forward strain of L5 on S1 until a stress fracture occurs through the lamina separating body, pedicles and superior articular processes from laminae, inferior articular processes and spinous process. This is spondylolysis. The anterior portion is now free from the locking mechanism of the inferior processes over the superior processes of the sacrum and can move forward carrying the rest of the vertebral column with it. This is spondylolisthesis.

Plate 3. Specimen of bilateral spondylolysis of last presacral vertebra.

Probably the most common cause of spondylolisthesis without spondylolysis is degeneration of the articular joints of the vertebral column. If added to this the plane of articulation between L5 and S1 is more sagittal than frontal, the inferior processes of L5 slip through the superior processes of S1 on the medial side and the whole column then moves forward on the sacrum. The specimen illustrated is a good example of this condition, with the lengthened articulating surfaces of the inferior articular processes well seen. Protective bony outgrowths on the body of the sacrum and L5 to try to prevent the forward slide are also evident.

One specimen described in the literature showed such gross slipping that a bony ridge had been formed on the sacrum on which at least one third of the body of L5 was resting. In this instance it was thought to have caused the death of a patient by rupturing the uterus during labour.

Lastly, if the pedicle or laminae between the articular processes is rather elongated and thin, forward slipping is possible without a break in the bone, though this may occur later with increased strain. The disease osteogenesis imperfecta in children is one of the causes of the above.

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Plate 4. Specimen showing degenerative spondylolisthesis with bony proliferation on the bodies of L5 and S1.

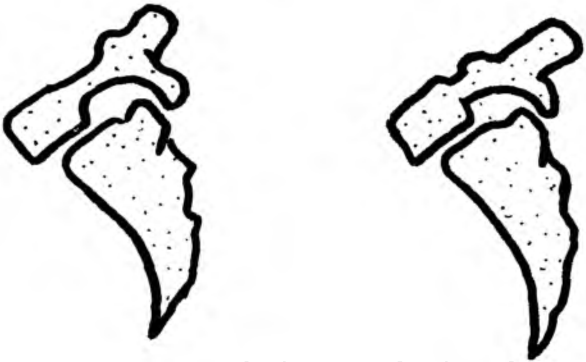

Fig. 9. Diagrams showing elongated pedicle and spondylolisthesis.

Three instances of spondylolisthesis in the cervical spine have been recorded, in conjunction with spina bifida.

This raises the question whether there is a heriditary or congenital factor in the causation of spondylolysis. Heriditary instances have been sited both in families and population groups and it is known to occur in conjunction with spina bifida. However it has not been seen in the new-born and has been recorded as having developed over a period of years observing a spondylolisthesis first. It may be that the heriditary factor is due to the spina bifida and shallow articulating facets predisposing towards a weakness of ligamentous support of the area. With the strain of use, stress facture develops or L5 slips forward over the inadequate superior facets of S1. The theory that there are two ossification centres for the neural arch on either side and that spondylolysis is a failure of ossification of these two centres does not enjoy much support. However in the specimen illustrated the unilateral division of the laminae is not totally consistent with stress in the region which is more likely to cause a bilateral lesion. Furthermore the lamina on the interrupted side is very much thinner than on the uninterrupted side. It may be that some vascular deficiency was the cause of the faulty ossification here.

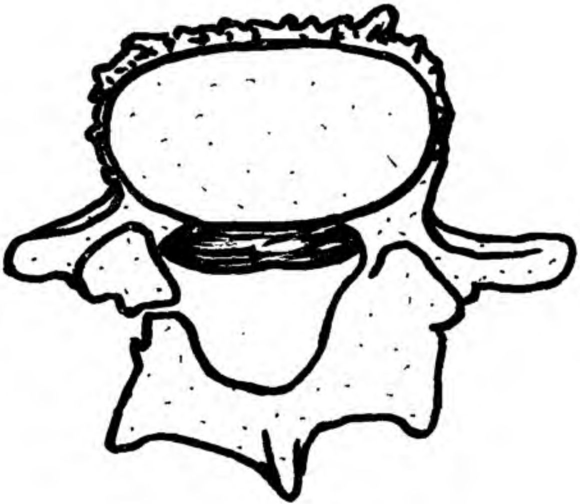

Fig. 10. Drawing from specimen showing unilateral spondylolysis.

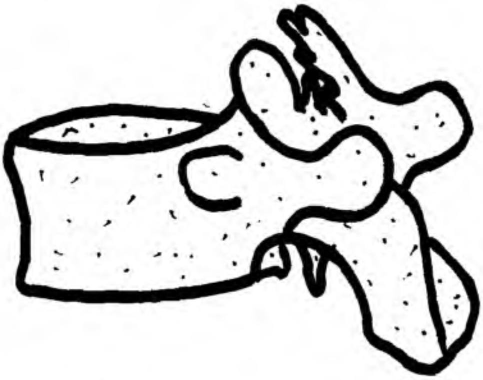

Fig. 11. Drawing from specimen showing spurs in ligamentum flavum.

Bony Spurs in the Ligamentum Flavum

These bony spurs have been recorded by several authors and the illustration here is from a specimen in the University of Cape Town collection, which also shows absence of the spinous process.

Bony outgrowths are seen on both the superior and inferior attachments of the ligamentum flavum. The most common site for these outgrowths is in the thoracic region where a dorsal curve already exists. As the function of this ligament is to check undue forward flexion it would seem that this is a reaction to strain in the area.

Other anomalies which are seen tend to be at the transitional levels of vertebrae related to the characteristics of the articular processes. For example L1 may exhibit the form of T12 articular processes. Increased or decreased mobility by one segment is not really remarkable. The deficiency in S1, superior articular facet has already been discussed in relation to spondylolisthesis.

SUMMARY

The ossification of the vertebral column is briefly discussed with bony abnormalities following developmental phenomena being shown, such as spina bifida, cervical rib and various anomalies of the lumbo-sacral junction.

Spondylolisthesis and spondylolysis is discussed with reference to causation from a stress fracture, degeneration of the joints of the vertebral arch and attenuated pedicles or pars inter-articularis. A note on the possibility of hereditary factors in this condition is added.

Other minor anomalies such as transverse foramen deficiencies in the cervical spine, differences in the plane of articular facets and spurs in the ligamentum flavum are noted.

One specimen of absence of the anterior arch of the atlas is described.

ACKNOWLEDGEMENTS

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