GROWTH AND DEVELOPMENT

OF THE

HUMAN INTERVERTEBRAL DISC

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Thesis for the degree of Doctor of Philosophy

in the Faculty of Medicine of the University of Edinburgh.

September 1973

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GROWTH AND DEVELOPMENT OF THE HUMAN INTERVERTEBRAL DISC

ABSTRACT

The object of this study is to compare the growth and development of a lumbar intervertebral disc with those in the thoracic and cervical regions from embryonic life to childhood. Particular attention is paid to changes during and following the establishment of the secondary curvatures of the vertebral column. Current knowledge of development of the intervertebral disc is reviewed.

Postmortem material from 67 cases and a large series of radiographs are used in histological and mensural studies. The vertical dimensions of the 'total disc' (which includes the cartilage plates), its parts, and the vertebral body above the disc are measured in each region at every age. Notochordal remnants in vertebrae and discs are used as 'natural markers' from which horizontal dimensions are measured in the median plane to give an indication of growth anteriorly and posteriorly from the position of the notochord.

Notochordal cells appear to multiply during foetal life and infancy, playing an important role in growth and extension of the notochordal nucleus pulposus up to about three years, but they degenerate and disappear from about three to seven years.

As the notochordal nucleus pulposus grows rapidly in

volume, principally by increase in its mucoid matrix (notably in lumbar discs), the anulus fibrosus and cartilage plates bounding it become thinner. Associated with thinning of the cartilage plates, vertical growth of the central part of the 'total disc' slows down during the first two postnatal years.

As secondary cervical and lumbar curvatures are established, the cervical and lumbar notochordal nuclei pulposi respectively move to more anterior and central positions, but the thoracic notochordal nucleus pulposus remains posteriorly situated. From two years onwards, the central parts of lumbar discs grow rapidly in height though the heights of the central parts of thoracic discs remain almost unchanged. The central situation of the lumbar nucleus pulposus in childhood, and the rapid increase in height of the central part of the lumbar 'total disc' from two to seven years are associated with corresponding changes in the shape of the cephalic and caudal end surfaces of lumbar vertebral bodies from convexity to concavity.

During the same period (about two to seven years) there is an increase in the rate of antero-posterior growth of the lumbar vertebral column without any increase in its lateral growth rate.

The present investigation throws further light on the work of Houston and Zaleski (1967) who demonstrate a relationship between 'activity' and vertebral body shape, and suggests that the rate of anteroposterior growth of the lumbar vertebral column, the

the rate of vertical growth of lumbar vertebrae and 'total discs', and their changes in shape during childhood, all depend to some extent on the assumption of the normal erect posture.

GROWTH AND DEVELOPMENT OF THE HUMAN INTERVERTEBRAL DISC

GENERAL INTRODUCTION

This study is undertaken in order to -

1. Extend anatomical knowledge of the developing intervertebral disc.
2. To study the developmental anatomy and growth of intervertebral discs and by -
   (i) measurement of discs at different ages to study their horizontal and vertical growth
   (ii) comparison of growth and development in cervical, thoracic, and lumbar discs to link regional variations in structure to regional variations in posture.

1. Extension of anatomical knowledge

a) Range of Study:

Previous studies mostly deal with prenatal development of the intervertebral disc. Relatively few investigations of postnatal development are published, and these describe only a few cases in the first decade of life. Prader (1945) remarks that most early descriptions of disc development are based on observations of single specimens, and Peacock (1951) comments that apart from Prader's work no contribution deals specifically with the development of the intervertebral disc as a whole.

No comparative study of development of the intervertebral disc in different regions of the vertebral column appears to have been undertaken, though a few comments on regional differences are found scattered throughout the literature.

Thus it appears desirable to study a more comprehensive series of discs in the first decade of life. A regional comparison is required at all stages of development.

b) Method of Study:

Histological changes in the developing intervertebral discs are fairly well documented, but measurement of the changes in the dimensions of the intervertebral disc has not been previously attempted. Measurement can provide objective evidence of the extent of some developmental changes in discs from different regions of the same individual, and enables valid comparisons to be made. Thick sections of celloidin embedded material are more convenient in this study than the thin wax embedded sections used by most previous authors, since i) many large blocks of tissue can be surveyed by examining a reasonably small number of sections, and ii) measurement rather than detailed histological examination is the principal method of study.

c) Subject of Study:

No single part of the disc can be studied in isolation, particularly during its development. However, the most dramatic developmental changes occur in the nucleus pulposus. Since

Luschka's first description of the nucleus pulposus (1852), controversy on the role of the notochord has persisted. Different authors describe discs from different regions of the vertebral column, and many do not specify the region studied. Particular attention is paid in the present work to the development of the nucleus pulposus and the role of the notochord. Regional comparison may resolve some of the conflicting views on these matters.

2. Developmental Anatomy and Later Degenerative Change:

A number of authors have attempted to relate the pathology of the intervertebral disc to its development - inter alia: Ehrenhaft (1943), and Coventry, Ghormley, and Kernohan (1945). Schmorl and Junghanns give a comprehensive review of the embryology anatomy and pathology of the vertebral column in their monograph entitled "The Human Spine in Health and Disease" (1959). Böhmig (1930) relates the notochord, and the blood vessels of developing discs, to the occurrence of Schmorl's nodes in the adult.

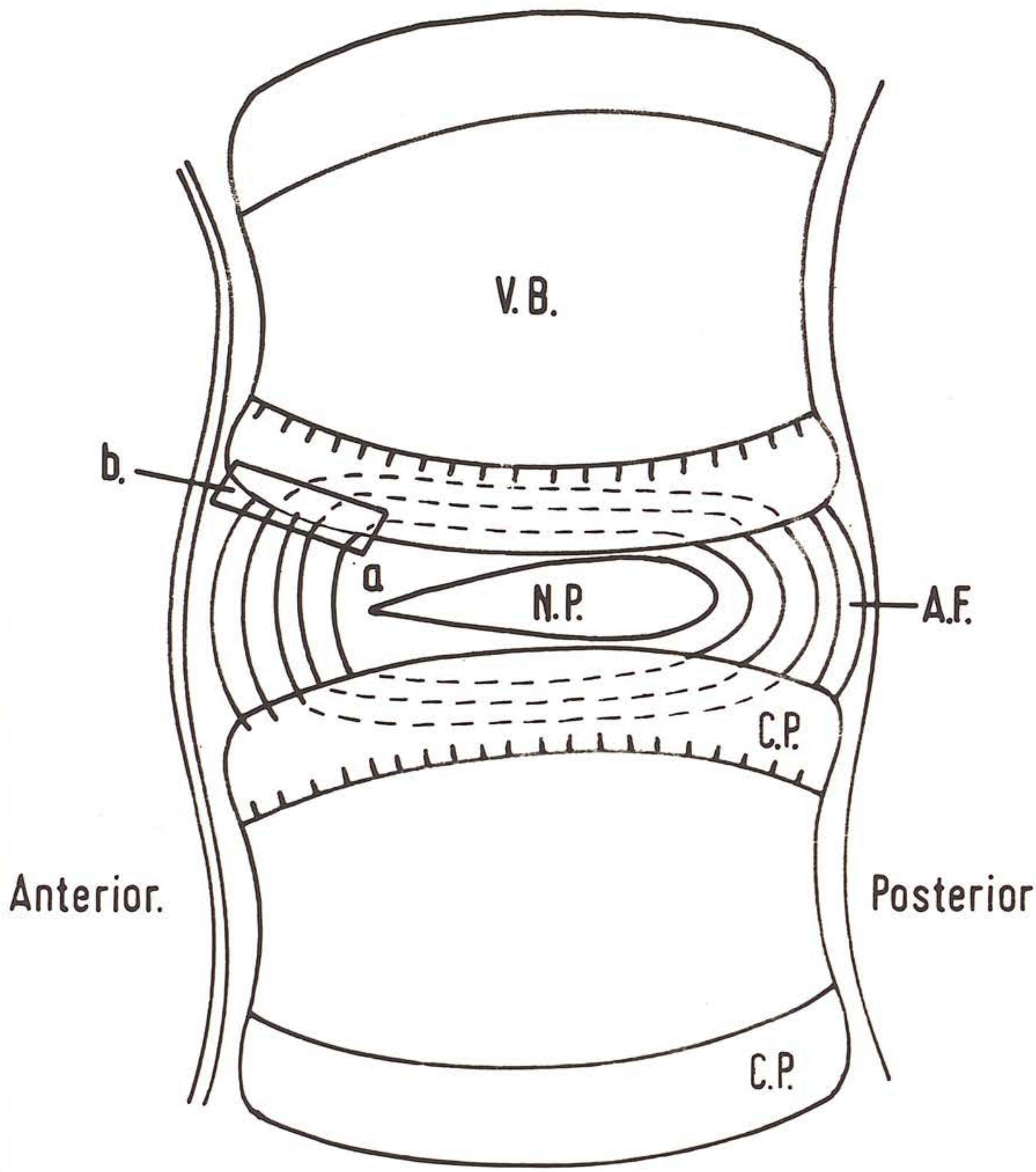
Degenerative changes in the intervertebral disc occur in middle and late adult life. In the past two decades the frequency of such degenerative changes, and their association with low back pain and shoulder, neck and brachial pain have been emphasised by many authors. Almost two thirds of the adult population in Western European countries show radiological evidence of disc degeneration. (Hult, 1954; Lawrence, 1969). Symptoms are most frequently referable to lower cervical or lower lumbar discs.

These situations correspond to the maximal secondary curvatures of the vertebral column which are established during infancy and childhood. In view of these considerations, a study of lower lumbar and lower cervical discs in foetuses, infants and children appears to be justified, with a survey of mid-thoracic discs where the primary curvature is maintained, for comparison.

It is not proposed to study the intervertebral disc in isolation. Where appropriate, growth and development of vertebral centra and cartilage plates will also be studied.

Text-fig. 1

DIAGRAM of INTERVERTEBRAL DISC and VERTEBRAL BODY of NEWBORN INFANT.



A BRIEF REVIEW OF THE PRESENT STATE OF KNOWLEDGE

A. General Description and Nomenclature:

In the adult, the intervertebral discs form a quarter of the total length of the presacral vertebral column (Cunningham, 1972). According to Schmorl and Junghanns (1959) the average height of the disc is one third of that of the adjacent vertebral body. Cervical and lumbar discs are relatively thicker than thoracic discs. The anterior height of cervical and lumbar discs exceeds their posterior height and this is largely responsible for the secondary curvatures developed in these regions.

In standard anatomical texts, (Gray, 1967; Cunningham, 1972) the intervertebral disc is described as consisting of a peripheral anulus fibrosus and a central nucleus pulposus. The intervertebral disc, and particularly its nucleus, undergoes continuous change during its development, maturation, and degeneration. For example, the prenatal notochordal nucleus becomes the fibrocartilaginous nucleus of adult life. The fibrous anulus, relatively vascular in foetal and infant life, becomes almost avascular in adults.

The description of the disc as comprising an anulus fibrosus and a nucleus pulposus is regarded as oversimplified by Peacock (1952). In the prenatal disc Peacock describes a 'transitional zone' Text fig. 1 (a), of randomly oriented fibrocartilage lying between the anulus and the nucleus. This zone is often referred to as the "inner cell zone" (Peacock, 1951; Walmsley, 1953).

The 'inner cell zone' disappears in the post natal disc. Some authors describe an additional "transitional zone" (b) where the fibres of the anulus enter the peripheral parts of the adjacent cartilage plates. Franceschini (1947) regards the fibres of the anulus as continuing around above and below the nucleus, completely encapsulating it. (Text fig. 1). In the lamellar anulus, fibrous outer lamellae can be distinguished from fibrocartilaginous inner layers. In foetal and infant discs, the boundaries of the mucoid 'notochordal' nucleus are clearly defined, but in the mature disc it is impossible to determine an exact boundary line between the fibrocartilaginous nucleus and the inner fibrocartilaginous anulus by histological means.

Historically, the cartilage plates capping the ends of the adjacent bony vertebral bodies are regarded as parts of the intervertebral disc (Schmorl, 1928; Böhmig, 1930), but most recent authors and standard anatomical texts maintain that they are parts of the vertebral bodies (Walmsley, 1953). Putschar (1959) considers that although the cartilage plates are embryologically parts of the vertebral body, they are functionally parts of the intervertebral disc. Such controversy as to disc and vertebral boundaries is not surprising in view of their common origin from a single continuous mesenchymal vertebral column. Whatever the status of the cartilage plates, the development of the anulus fibrosus and of the nucleus pulposus cannot be described adequately without reference to the concurrent development of the intimately related cartilage plates.

It is surprising that in classical descriptions of the development of the intervertebral disc (Prader, 1945; Prader, 1947 a) and b); Peacock, 1951; Peacock, 1952), scant attention is paid to the cartilage plates.

B. Early Development:

The first axial structures to appear in the embryo are the notochord and the neural tube. The vertebral column is formed by the condensation of mesenchyme around these axial structures. Descriptions of early development of the vertebral column are given by Wyburn (1944), Prader (1947a), Sensenig (1949), Peacock (1951) and Walmsley (1953). Bardeen (1905) describes the stages of development of the vertebral column as:

a) blastemal, b) chondrogenous and c) osseogenous.

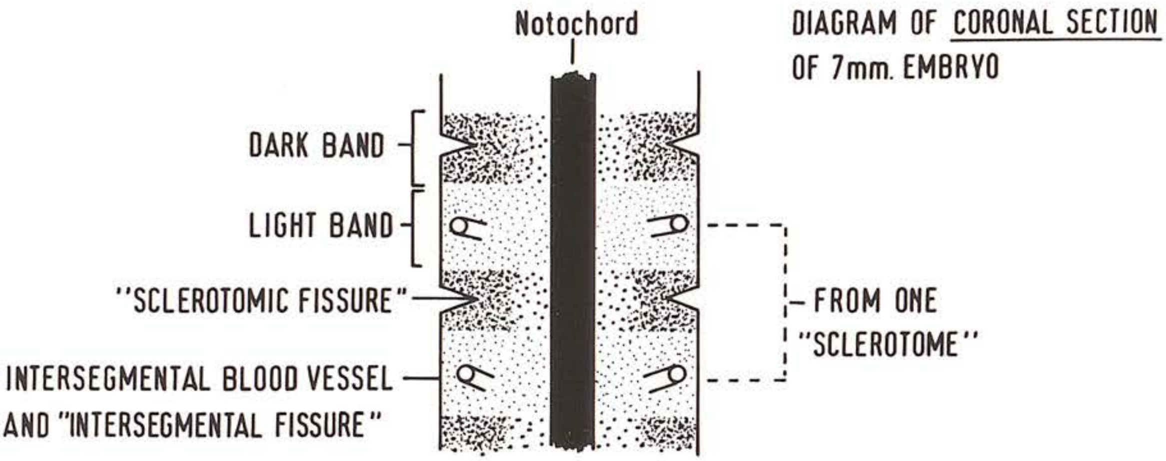
The earlier development of the elements of the vertebral column may be conveniently described using this classification:

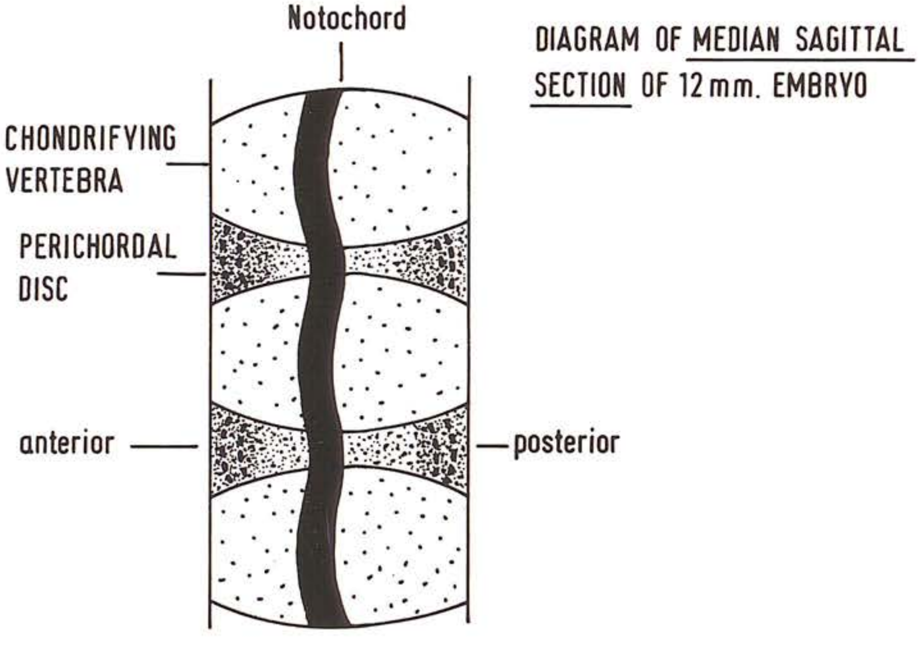
a) Blastemal stage:

In embryos of 2mm or more C.R.L. (3 weeks gestation) a continuous mesenchymal column is formed around the cylindrical notochord. This is due to the active proliferation and medial migration of the cells in the dense ventro-medial portions of the somites - termed sclerotomes by Goodsir (1857). The notochord, originally in contact with the gut tube ventrally and the neural tube dorsally, becomes separated from these structures as the sclerotomal cells migrate medially to surround it. The column is not formed simultaneously at all levels but appears first cranially and at a later stage caudally (Sensenig, 1949). Neural processes appear as condensations of mesenchyme extending dorsally from this continuous column, at each side of the neural tube. This continuous blastemal or membranous column around the notochord constitutes the anlage of the vertebral bodies and intervertebral discs.

In embryos of about 4 mm. C.R.L. a sclerotomic fissure appears at mid-segmental level (Bardeen, 1905; Wyburn, 1944; Prader, 1947a; Sensenig, 1949; Peacock, 1951; Walmsley, 1953) - see Text fig. 2. Intersegmental vessels also appear which are said to occupy intersegmental fissures (Sensenig, 1949). Both fissures are transverse, peripherally situated and incomplete, the central part of the column remaining continuous throughout its length. They are associated with the "theory of resegmentation of Remak (1855)", (Walmsley, 1953) a vertebra being regarded as derived from adjacent cranial and caudal half sclerotomes. Some authors have denied the existence of the sclerotomic fissure (Froriep, 1886; Gadow and Abbott, 1895), or regarded it as artefactual (Baur, 1969). Certainly its existence appears to be transitory - it disappears at about 10 mm. It is illustrated by Wyburn (1944), Prader (1947a), Sensenig (1949), Peacock (1951) and Walmsley (1953). Walmsley describes it as a transverse incomplete loosening of the cells, lacking definition, and not extending medially as far as the notochord. Baur (1969) who denies its existence contends that the blastemal column remains continuous, and that segmentation occurs only at a later stage, when the vertebrae differentiate in their definitive positions.

Text-figs. 2 & 3


Notochord
DIAGRAM OF CORONAL SECTION
OF 7mm. EMBRYO
DARK BAND
LIGHT BAND
"SCLEROTOMIC FISSURE"
FROM ONE
"SCLEROTOME"
INTERSEGMENTAL BLOOD VESSEL
AND "INTERSEGMENTAL FISSURE"


Notochord
DIAGRAM OF MEDIAN SAGITTAL
SECTION OF 12 mm. EMBRYO
CHONDRIFYING
VERTEBRA
PERICHORDAL
DISC
anterior
posterior

Sensenig (1949) also emphasises the continuous nature of the central part of the blastemal column.

A banded pattern becomes evident in the mesenchymal vertebral column of embryos of about 5 mm. C.R.L. (Text fig. 2). Dark bands are formed around the notochord at the level of the sclerotomic fissure and these alternate with light bands at the level of the intersegmental vessels. The dark and light bands appear so because of a relative density of nuclei with closely packed cells in the dark bands, and a less dense arrangement in the light bands. The dark bands are the forerunners of the intervertebral discs and the cartilage end plates and are known as the perichordal discs. The light bands are said to be the anlagen of the vertebral bodies. Dark and light bands are originally of equal height (Walmsley, 1953), but the light bands grow in height more rapidly than the dark bands. The immediate perichordal part of the 'dark band' remains 'light' or less dense throughout the column.

b) Chondrogenous stage:

In embryos of 10-12 mm. C.R.L. (at about 6 weeks gestation), the onset of chonrification in the light bands is reported (Sensenig, 1949; Peacock, 1951). This results in the rapid increase in their height which occurs during the sixth week of gestation. The light bands or primitive vertebral bodies also change their shape becoming convex at their cranial and caudal ends. Their increase in height is attributed partly to the chondrogenetic activity of the cells on the cranial and caudal aspects of the dark band or perichordal disc (Walmsley, 1953). The perichordal disc in the 12.5 mm embryo consists of three zones: an intermediate darker zone with lighter strips cranial and caudal to it adjoining the primitive vertebrae (Wyburn, 1944). At the same time, the outer mesenchymal cells of the perichordal disc begin to assume a lamellar arrangement, arranged with their long axes parallel to the cranio-caudal axis of the embryo.

In median sagittal sections the notochord begins to show a sinuous appearance, with dorsal concavities in the vertebra, and dorsal convexities in the perichordal disc (Walmsley, 1953) - Text fig. 3. These segmental flexures of the notochord are said to be best developed at 12 mm and have disappeared by the 18-20 mm stage. In a 17 mm embryo (7 weeks gestation) Walmsley (1953) reports that the notochord, still of relatively uniform diameter, shows a localised aggregation of cells within it at the intervertebral level, but the segmental dilatations of the notochord are first seen in embryos of about 20 mm. C.R.L. (Peacock, 1951; Walmsley, 1953).

In embryos of 20-40 mm C.R.L. the perichordal disc is a short cylinder, concave cranially and caudally. It has an outer dark lamellar zone of fibroblasts, the primitive anulus fibrosus, and a light 'inner cell zone' bounding a fusiform or rhomboidal dilatation of the notochord. Notochordal cells gradually disappear from the cartilaginous vertebral body leaving the 'notochordal sheath' or 'mucoid streak'. (Prader, 1945; Peacock, 1951).

c) Osseogenous stage:

In embryos of 40-50 mm. C.R.L. the mucoid streak or notochordal track through the vertebra is interrupted by chondrocyte hypertrophy and the onset of ossification. The streak gradually disappears as the endochondral ossification in the bony vertebral body progresses. Traces of the notochordal track may persist in the cartilage plates into postnatal life (Böhmig, 1930). The notochordal segment by its expansion within the perichordal disc appears to give rise to the nucleus pulposus.

Segmental Variations in the Notochord before the 20 mm. Stage:

1) Segmental flexures:

Transitory 'chordaflexures' are described by Dursy (1869) in man and other mammalian embryos. This early sinuous appearance of the unsegmented notochord has occupied the attention of numerous authors, who observe the flexures in embryos as early as 6 mm. and as late as 20 mm. (Minot, 1907; Sensenig, 1949; Peacock, 1951; Walmsley, 1953; Verbout, 1971). Prader reviews earlier descriptions of these chordaflexures. He finds them in human embryos between 6 and 12 mm. and agrees with Dursy in attributing their existence to a relative excess of growth in length of the 'chorda' compared with the vertebral column.

2) Dursy (1869) describes transitory spindle shaped swellings of the notochord in the vertebral body anlagen of a 12 mm bovine embryo. Williams (1908) states that similar notochordal swellings are found in the precartilaginous vertebrae of many mammalian embryos.

3) Sensenig (1949) claims that in human embryos as early as 10 mm. slight segmental differences in thoracic notochordal diameter can be detected, with the notochord up to 10% wider in the perichordal disc than in the vertebral body anlage.

C. FURTHER DEVELOPMENT OF THE ANULUS FIBROSUS

a) Differentiation and Growth

In 10-15 mm. embryos the elongated cells of the outer zone of the perichordal disc become oriented to give an outwardly convex curved lamellar pattern. (Prader, 1947b; Peacock, 1951; Walmsley, 1953). Collagen fibres first appear in this zone in embryos of 20-40 mm (Prader, 1947b; Peacock, 1951). This outer lamellar zone constitutes the anulus fibrosus. As the anulus develops in the foetus its outer part becomes almost entirely fibrous, with a concomitant decrease in its cellularity (Dahmen, 1965), while the inner part, though lamellar, remains more cellular becoming fibrocartilaginous (Prader, 1947b; Peacock, 1951; Walmsley, 1953). The outer fibrous anulus is fused with the longitudinal ligaments of the vertebral column (Walmsley, 1953). In the foetus, the intervertebral disc is bounded on its cephalic and caudal aspects by the cartilaginous plates of the adjacent vertebral bodies, and the fibres of the anulus are anchored to these plates. Polarised light studies reveal the continuity of the horizontal fibrous structure of the cartilage plates with the curved lamellar pattern of the anulus fibrosus. Together these structures encapsulate the nucleus pulposus (Franceschini, 1947); But (1959) defines the intervertebral disc of the 2 month embryo as including 3 zones: 1) an outer fibrous zone; 2) an intermediate fibrocartilaginous zone; and 3) an inner hyaline cartilaginous perichordal zone, the 'inner cell zone' of other authors. The inner cell zone around the notochord does not show any lamellar arrangement and is termed "precartilage" by Walmsley (1953), specialised embryonic cartilage by Peacock (1951), and hyaline cartilage by Prader (1947b) and But (1959). This zone becomes fibrocartilaginous in late foetal life (Prader, 1947b; Peacock, 1951), and it is said to contribute both to growth of the anulus fibrosus and the nucleus pulposus (Prader, 1947b; Peacock, 1951). Hirsch and Schazowicz (1953) state that growth of the anulus is both interstitial and appositional from the longitudinal ligaments of the vertebral column. Bohmig (1930) and Donisch and Trapp (1971) suggest that the anulus grows "interstitially from the cartilage plates", and relate this growth to the presence of vascular canals in the cartilage plates close to the anulus. This appears to be a contradiction in terms unless the anulus is redefined as extending through the cartilage plate. Walmsley (1953) states that growth of the anterior part of the anulus exceeds that of its posterior part. Horton (1958) believes that the anulus grows by increase in thickness of its lamellae and not by increase in the number of lamellae.

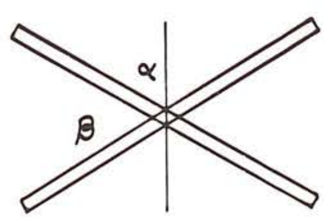
b) Fibre Pattern

In a 40 mm embryo the fibres and cells of each lamella pass in a curved spiral sheet from one cartilaginous vertebra to the opposite vertebra, and since fibres in adjacent lamellae lie at different angles, a cruciate pattern of fibres is seen in vertical sections of the outer zone of the disc (Peacock, 1951; Walmsley, 1953). Uebermuth (1929) believed that the outward convexity of the lamellae was due to mechanical causes such as the outward pressure of the notochordal aggregations. Prader (1945), Peacock (1951), and Walmsley (1953) point out that the outward convexity of the anulus is apparent before segmental dilatations of the notochord appear. Walmsley regards the pattern of the anulus as genetically determined. However, Prader (1945) and Peacock (1951) attribute the segmental changes of the notochord to mechanical causes.

The adult pattern is established in the anulus before birth, the inner cell zone being reduced and gradually disappearing, either by differentiation into lamellar fibrocartilage, or by liquefaction and incorporation into the nucleus pulposus. (Prader, 1947b; Peacock, 1951). Walmsley (1953) emphasises the complexity of fibre pattern in the anulus by stating that it 'almost defies description'. However in the lumbar intervertebral disc he describes 12 to 16 lamellae. Although lamellae do not form complete rings there is a pattern of dovetailing and anastomosis between them (Walmsley, 1953). From one cartilage plate, the majority of fibres spiral round the nucleus pulposus to sink into the opposite cartilage plate, but some fibres pass out into the longitudinal ligaments, and some pass into the anterior surface of the adjacent vertebral body (Beadle, 1931). Franceschini (1947), using polarised light, finds that the fibrous structure completely encloses the nucleus pulposus, passing through the cartilage plates. This 'anulus' resembles a flattened sphere which Franceschini (1947) describes as a 'parallelopiped'. Franceschini (1947) and Walmsley (1953) state that the innermost lamellae of the mature anulus may be convex inwards towards the nucleus. It is possible that this configuration is an artefact due to contraction of the nucleus during dehydration and embedding.

At about eight years a ring epiphysis forms in the periphery of each cartilaginous plate. Many fibres of the anulus gain attachment to this ring epiphysis, and subsequently, with its fusion at about 25 years to the vertebral body, to the bony rim of the vertebra.

Rouvière (1921) and Horton (1958) studied the angle between fibres of adjacent lamellae of the anulus fibrosus. The angle " " between the fibres and the vertical measures 50^{o} in cervical and thoracic discs, increasing to 60^{o} in lumbar discs. The greater angle in lower discs is said to reflect the greater weight borne by them (Rouvière, 1921). These angles do not change from infancy to adult life. Horton (1958) describes the 'interstriation angle' " " as about 57^{o}, decreasing in experiments on autopsy discs with vertical compression of the intervertebral disc. Schmorl (1959) describes 'spanning fibres' binding adjacent lamellae together, but this has not been confirmed by other authors.



Text Figure 4

Walmsley (1953) describes a change in the orientation of the fibrous structure of the posterior anulus, as seen in median sagittal sections of lumbar discs, after establishment of the secondary lumbar curvature. In the infant the fibres pass in a gentle curve from the upper to the lower vertebra, but in the child of eleven years they are said to pass in a sharply curved or U-shaped course between the vertebrae.

D. DEVELOPMENT OF THE NUCLEUS PULPOSUS

a) Role of the notochord in the origin of the nucleus pulposus.

According to Williams (1908), Luschka gives the first detailed account of the formation of the nucleus pulposus. Luschka (1852) states that the nucleus pulposus arises from the intervertebral expansions of the notochord. Virchow (1857) suggests a different origin, the nucleus arising "through a central growth of cartilage with softening of its ground substance ". In 1858, Luschka, while still maintaining that the intervertebral expansion of the notochord forms the original nucleus pulposus, accepts that it is later augmented by the liquefaction of fibro-cartilaginous processes from the surrounding parts of the inter-vertebral disc. Kölliker (1861 & 1879) also describes the origin of the nucleus pulposus from the notochord in man and other mammals. Robin (1868) upholds the views of Luschka and Kölliker on the noto-chordal origin of the nucleus (although he is quoted as having taken a contrary view by Williams (1908), Keyes and Compere (1932), and Walmsley (1953). Dursy (1869) is supported by Leboucq (1880) in regarding the role of the notochord in human nucleus pulposus formation as minimal and confined to the early embryonic stages of development. These early authors had wide experience of non-human, mammalian material but had few human embryonic specimens at their disposal. Moreover, Dursy confines his observations in man to the development of the cervical region of the vertebral column.

More recent studies (though often lacking regional precision or comparison in their descriptions of development) are based on observations of extensive series of human embryos. These agree that the notochord plays an essential role in the origin of the nucleus pulposus, and that it continues to do so in the development of the nucleus at least during the first half of prenatal life (Prader, 1945; Sensenig, 1949; Peacock, 1951; Walmsley, 1953; But, 1959). Some also attribute a role to the notochordal cells in postnatal life (Malinski, 1958; Wolfe, Putschar & Vickery, 1965).

As stated earlier, notochordal dilatations at the level of the perichordal disc appear at the 20 mm stage of human embryonic development and increase progressively in size. Recognisable notochordal cells disappear from the intravertebral course of the notochord leaving the notochordal sheath - a clear homogenous cell free strand - as a "mucoid streak" through the centre of the primitive cartilaginous vertebral body. Kölliker (1879), Williams (1908), Schaffer (1910), Keyes and Compere (1932), Prader (1945), Sensenig (1949), and Peacock (1951) attribute the segmental changes of the notochord to passive displacement of the notochordal cells from rapidly growing cartilaginous vertebral bodies to looser, more slowly growing adjacent perichordal discs. Walmsley (1953) believes that active multiplication of notochordal cells in the discs and concurrent death of cells in the vertebral bodies account for the segmental changes. He instances a 17 mm embryo where the notochord is still of uniform diameter, but a greater cell density is seen at intervertebral levels compared with vertebral levels.

The notochordal dilatations in the perichordal discs are usually fusiform or rhomboidal in shape. (Böhmig, 1930; Prader, 1945). Böhmig (1930) describes a variety of shapes of 'chorda-segment' as seen in an 86 mm embryo, particularly:- "rhombusform", "pilzform", and "stabform", but also a "V-form" or "dachform" shape, usually found in the cervical region. Peacock (1951) was unable to find such well-defined forms in his series but, in agreement with Prader (1945), describes a horizontal expansion of the notochord segment which takes place in embryos of 30-100 mm C.R.L.. This notochordal expansion is predominantly in a posterior or dorsal direction.

Soon after notochordal segmentation, extracellular matrix appears around the notochordal cells. Robin (1868) states that the central cavity of the intervertebral disc is produced by expansion of the notochordal segments with multiplication of the notochordal cells and the appearance of a gelatinous matrix which separates the cell mass into small clumps. Different authors note the first appearance of extracellular substance in embryos at various stages between 20 and 55 mm C.R.L. (Prader, 1945; Bradford and Spurling, 1945; Peacock, 1951; Walmsley, 1953; But, 1959). At the same time a change in the appearance of the notochordal cells is described with the appearance of vacuoles or vesicles in their cytoplasm. Thus Virchow (1857) describes chordoma cells as "physaliferous" (or "bubble-bearing"), though he mistook the origin of the chordoma, and referred to it as a tumour of cartilage. Robin (1868) described the appearance of "sarcoid droplets" in the notochordal cells from three months of intrauterine life (about 100 mm) onwards. Prader (1945), Bradford and Spurling (1945), Peacock (1951), and But (1959) also describe the appearance of intracellular vesicles in the notochordal cells of embryos of from 21-70 mm onwards. Thereafter increasing quantities of "mucoid matrix" of similar appearance to the substance in the intracellular vacuoles (Walmsley, 1953) appear around the notochordal cells. The accumulation of matrix splits up the originally compact mass of notochordal cells into cellular clumps and strands - a loose network known as the "chorda reticulum" (Peacock, 1951). The earlier view that the notochordal cells formed a sycnytium (Williams, 1908; Link, 1910; Walmsley, 1953) has not been confirmed by electron microscopy. In the rabbit embryo (Leeson, 1958) and the chick embryo (Jurand, 1962) cells membranes are complete at all stages of notochordal cell development.

b) Survival of notochordal cells

Some authors regard the appearance of vesicles in the notochordal cells as a sign of degeneration (Link, 1910; Böhmig, 1930; Keyes and Compere, 1932) referring the increase of matrix to mucoid degeneration of notochordal cells. As a result of *in vitro* experiments on fresh notochordal cells Robin (1868) considers the accumulation and disappearance of droplets in these cells to be a reversible process.

There is wide divergance in estimates of the period during which notochordal cells continue to survive, multiply or show other activity. Prader (1945) observes mitoses only in notochordal cells of his earliest group of embryos (3-5 mm). He describes 'involutional changes' (pyknotic nuclei and acidophilic cytoplasm) from 70 mm onwards, and although he observes 'clearly recognisable notochordal cells' in full term foetuses all the cells 'show degenerative appearances'. Prader (1945) associates the degeneration of the vesicular notochordal cells with the accumulation of mucoid matrix. Bradford and Spurling (1945) claim that the notochordal cells are reduced in number by 157 mm and that they are inconspicuous in the 'full-term' nucleus pulposus. Peacock (1951) finds that notochordal cells are fewer in number by 210 mm although he describes the full term nucleus pulposus as still predominantly notochordal. But (1959) sees progressively increasing vacuolisation with shrinkage and destruction of notochordal cells in "foetuses" of 80 mm (crown-heel length).

Other workers attribute more prolonged activity to the cells. Keyes and Compere (1932) emphasize the rapid growth of notochordal tissue up to 157 mm maintaining that the notochord is the chief source of the nucleus pulposus up to full term. Walmsley (1953) believes that the notochordal cells increase 'in size and number' during the first six months of intrauterine life. Thereafter they degenerate, the full term nucleus pulposus consisting mainly of mucoid material containing 'scattered notochordal cells'. Malinski (1958) describes the chorda reticulum in full term foetuses as "widespread" and considers that notochordal cells are active in the production of mucopolysaccharides until the fifth or eighth year of post-natal life. From histochemical investigations on foetal and infant intervertebral discs, Wolfe Putschar and Vickery (1965) conclude also that notochordal cells contribute to the matrix in the postnatal period, probably by the production of mucopolysaccharides. Using autoradiography, Amprino (1955) and Souter and Taylor (1968 and 1970) show that notochordal cells in immature small mammals incorporate S^{35} sulphate, and conclude that the cells produce mucopolysaccharides.

Some earlier authors believe the human nucleus pulposus to be notochordal, even in the adult. Kölliker (1861) not only describes the newborn disc as "filled with a soft substance derived from the notochord", but also states that "in the adult, chorda cells in abundance are still to be found in the nucleus pulposus". Robin (1868) describes the atrophy of notochordal cells in embryonic vertebrae, vesicular changes in the 'growing and multiplying notochordal cells of the foetal disc', and the gradual degeneration and atrophy of the notochordal tissue 'in later childhood and adult life with final disappearance of the notochordal cells at about 60 years'. Nevertheless most modern authors agree that notochordal cells disappear from the human disc during infancy and childhood. Peacock (1952), and Walmsley (1953) could not detect any notochordal cells in discs in children of more than 10 years of age. Malinski (1958) does not observe notochordal cells in discs after the 8th year, and Meachim and Cornah (1970) in their study of the fine structure of the human juvenile nucleus pulposus find that most notochordal cells disappear by about 4 years of age. However, Schwabe (1933) describes persistence of notochordal tissue in adult sacral disc remnants, attributing their persistence in this situation to the 'absence of mechanical attrition'.

c) <u>Changes at the periphery of the notochord</u>

In the early embryo (c. 20 mm) a clear homogeneous notochordal sheath is described surrounding the original diamond shaped notochordal dilatation, (Kölliker, 1861; Prader, 1945; Peacock, 1951). This sheath initially separates the notochordal cells from the cells of the surrounding perichordal disc. As early as the 35 mm stage (Walmsley, 1953) the sheath may break down, leading to a "blending and interaction between notochordal cells and the cells of the inner cell zone". Walmsley (1953) describes active invasion of the inner cell zone by the notochordal cells, in a 72 mm embryo and postulates that degenerative changes observed in the cells of the inner zone are a direct result of this invasion. He suggests (as did Luschka in 1858) that by its degeneration and liquefaction the inner cell zone adds to the volume of the expanding nucleus pulposus. Keyes and Compere (1932), Prader (1945), Peacock (1951), and But (1959) also agree that interaction between notochordal cells and the cells of the surrounding inner cell zone plays an essential part in the growth and expansion of the nucleus pulposus. Indeed But (1959) maintains that the soft central mass cannot properly be called 'nucleus pulposus' until this interaction has taken place (in foetuses of 14-18 cm C.H.L.)

The first appearance of fine fibrous elements in the matrix of the nucleus pulposus is described by Walmsley (1953) in a 94 mm embryo, and by Keyes and Compere (1932) in a 157 mm specimen. Prader (1947) also reports "flaking off" of collagen fibres into the nucleus pulposus in a full term foetus, but the increase of collagen in the nucleus pulposus is most marked in postnatal rather than prenatal life (Peacock, 1952).

d) Postnatal changes in the nucleus pulposus

The newborn (lumbar) nucleus pulposus is relatively large with clearly demarcated margins, bounded by a fibrocartilaginous zone. Its matrix is an apparently homogeneous mucoid substance, containing scattered clumps and strands of notochordal cells. Although typical notochordal cells are seen, many notochordal cells show signs of degeneration (nuclear pyknosis and fragmentation). The innermost part of the surrounding fibrocartilage appears to be undergoing liquefaction. Similar but less obvious changes are occurring at the faces of the cartilage plates (Peacock, 1952).

The five month old nucleus pulposus has a similar appearance (Peacock, 1952). Luschka (1858) states that during childhood villous processes of fibrocartilage project into the notochordal nucleus. At one year the notochordal residue is still clearly recognisable, but fine collagen is appearing in the matrix of the nucleus (Amprino and Bairati, 1934). By four years an irregular network of collagen is seen in the matrix and only a few isolated clumps of notochordal cells persist, many of which are degenerate.

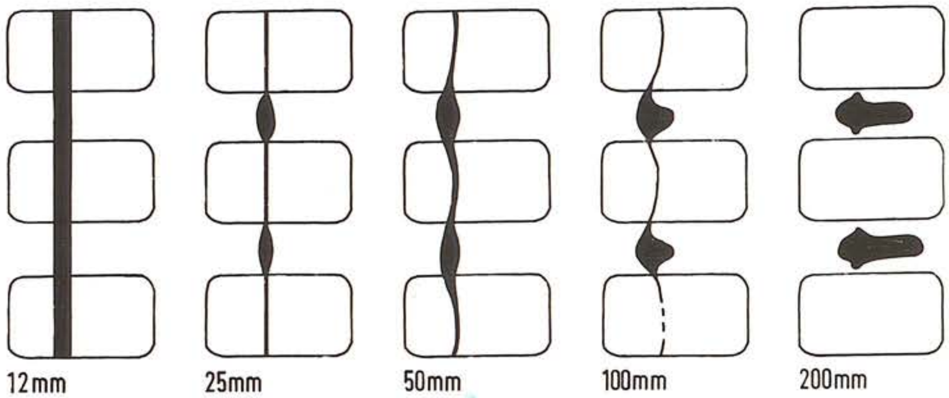
At all stages of infancy and childhood the nucleus pulposus occupies a large part of the area of a lumbar disc as seen in median sagittal section, but as age increases the boundary between the nucleus pulposus and the surrounding fibrocartilage becomes blurred, while the collagen fibre content of the nucleus increases (Peacock, 1952). The progressive increase in its collagen content and the gradual change in its cell content from large groups of notochordal cells in clumps or strands to relatively few cells resembling chondrocytes, occurring singly or in small groups, so alter the appearance of the nucleus pulposus during childhood that the nucleus of a young adult appears fibrocartilaginous (Amprino and Bairati, 1934; Peacock, 1952; Walmsley, 1953; Meachim and Cornah, 1970).

Corresponding with its histological changes during maturation, the water content of the nucleus decreases with age, from 88% in the newborn to 76% in the third decade of life, (Puschel, 1930). Nevertheless the young adult nucleus contains much mucoid substance, although its presence is masked by the irregular fibrocartilaginous network (Peacock, 1952). Nachemson (1960, 1970) maintains that

Text-fig. 5

DEVELOPMENT OF NOTOCHORD

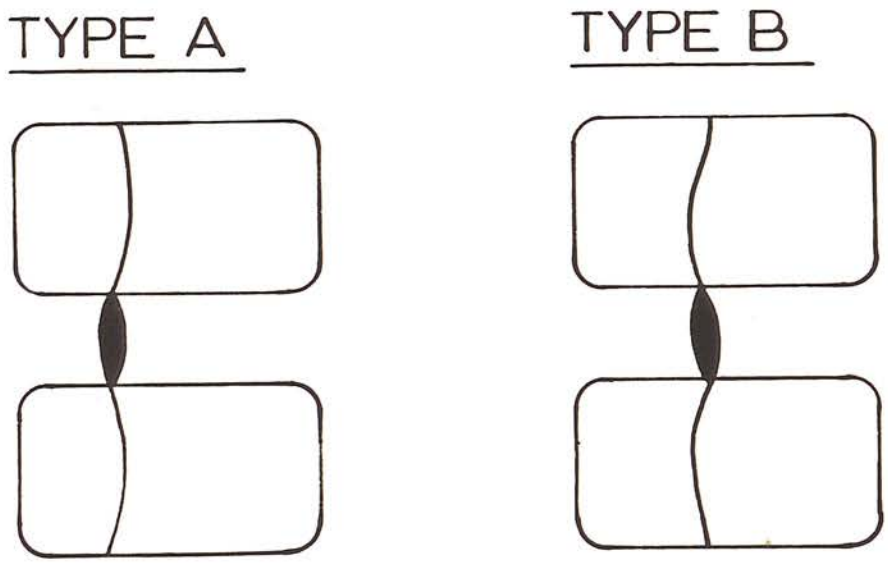
(Prader)



Text-fig. 6

NOTOCHORDAL FLEXURES

(Prader)



despite its dramatic change in appearance during postnatal development and maturation, the nucleus pulposus of the normal adult still behaves as a fluid, distributing compression forces equally in all directions to the cartilage plates and anulus fibrosus. That the nucleus pulposus is under pressure in the absence of any external load is shown by the fact that it bulges out from the cut surface on section of the disc (Charnley, 1952), the internal pressure 'in vivo' exceeding the external load by 50% (Nachemson, 1970).

Almost two thirds of the adult population are said to show radiological signs of disc degeneration, (Hult, 1954; Lawrence, 1969). According to Stevens (1968) the basis of this is that the loss of water content and decreasing turgor of the nucleus lead to horizontal bulging of the anulus, and stripping of the periosteum from the vertebral body margins, with the formation of osteophytes. The fact that the nucleus pulposus is avascular throughout life, (Peacock, 1952; Walmsley, 1953) and that the blood vessels in the cartilage plate gradually disappear by early adult life (Uebermuth, 1929; Bohmig, 1930) would also seem to be important in relation to such 'disc degeneration'.

e) The position of the notochordal segments and nucleus pulposus within the intervertebral disc

i. In the prenatal disc:

In 10-72 mm embryos the notochord lies anterior to the centre of the vertebral column (Keyes & Compere, 1932; Prader, 1945; Peacock, 1951; Walmsley, 1953; But, 1959) - see Text fig. 5. In the discs posterior expansion takes place from the original anterior position. By its enlargement, as seen in the median plane the nucleus pulposus comes to occupy half the antero-posterior extent of the disc in a 210 mm embryo (Peacock, 1951). Prader (1945) attributes this predominantly posterior expansion to a lesser tissue pressure in the posterior parts of the kyphotic foetal vertebral column.

Notochordal flexures, quite distinct from those previously described in the unsegmented notochord, are described in older embryos where the mucoid streak is still visible (up to 150 mm). These are seen in the later cartilaginous and early ossification stages of vertebral development, (c. 35 - 150 mm) and are said to be due to the fixed position of the mucoid streak in the ossifying vertebral body, while the notochordal segment in the disc shifts its position (Schaffer, 1910). Two different types of flexure are described, designated "type A" and "type B" by Prader (1945) - see Text fig. 6. Type A shows a dorsal convexity in the vertebral body and a ventral angulation in the disc, and Type B shows the opposite configuration.

Most early descriptions of these later chordaflexures are based on observations in embryos of mammals other than man (Dursy, 1869; Kölliker, 1859 - cited by Schaffer, 1910; Carlier, 1890; Schaffer, 1910). In these mammals chordaflexures of Type B are usually described, though Carlier (1890) and Schaffer (1910) maintain that the chordaflexures vary according to the region of the vertebral column where they are found. In human embryos, Dursy (1869) describes flexures of Type A in the cervical region, Bohmig (1930) states that usually flexures of Type A are found, and Prader (1945) holds that only Type A flexures are found in all regions of the human vertebral column (embryos of 35 - 150 mm).

ii. Position of the nucleus in the postnatal disc:

Peacock (1952) describes the nucleus pulposus of the lumbar disc as central in position during the first decade of life but nearer the posterior than the anterior surface thereafter. Keyes and Compere (1932) describe the adult nucleus as being eccentric in position with its main mass posterior of centre (without any regional qualification). Walmsley (1953) states that the adult nucleus is centrally situated in cervical and thoracic discs, but posterior of centre in lumbar discs, the apparent backward shift of the lumbar nucleus being due to greater growth in thickness of the anterior anulus fibrosus as compared to the posterior anulus. Böhmig (1930), Putschar (1959) and But (1959) maintain that the position of the nucleus is influenced by the curvature of the vertebral column, being posterior in kyphotic regions and anterior in lordotic regions.

E. THE CARTILAGE PLATES

These hyaline cartilages cap the cephalic and caudal surfaces of the vertebral bodies. Many authors have regarded them as part of the intervertebral disc: (Böhmig, 1930; Schmorl, 1928; Beadle, 1931; Geist, 1931; Amprino & Bairati, 1934; Coventry et al, 1945; Harris & McNab, 1954; Coventry, 1969) but most recent authors (Prader, 1947b; Peacock, 1952; Walmsley, 1953; Tondury, 1958) and standard anatomical texts (Gray, 1967; Cunningham, 1972) describe them as the cartilaginous plates of the vertebral bodies. In the following review, the orthodox convention (excluding the C.P.s from the I.V.D.), will be followed.

a) Origin and Role in the Growth of the Vertebral Column

At an early stage of development (12.5 mm), the mesenchymal tissue of the dark band between the developing cartilaginous vertebral bodies - the perichordal disc - consists of three parts (Wyburn, 1944): a middle component or plate, the anlage of the intervertebral disc, and cranial and caudal components or plates. The latter are changed by extension of chondrification from the vertebral bodies and become the primordia of the cartilage plates (Wyburn, 1944; Peacock, 1951).

Once ossification has begun in the vertebral bodies, the cartilage plates fit over the cephalic and caudal surfaces of the bony vertebral body "as an overhanging lid fits a jampot" (Schmorl & Junghanns, 1959). The cartilage plates in foetuses infants and children may be regarded as including: a) the growth zone with its palisade arrangement of cartilage cells in columns vertical to the advancing ossification front of the vertebral body, and b) a layer of hyaline cartilage with flattened cells oriented horizontally, adjacent to the intervertebral disc. Each 'cartilage layer' has the fibres of the anulus fibrosus anchored in it peripherally, and bounds the nucleus pulposus centrally (Coventry et al, 1945; Peacock, 1952; Walmsley, 1953; Harris and MacNab, 1954; Schmorl & Junghanns, 1959).

Small blood vessels which penetrate the cartilage plates from the periphery from the 93 mm stage onwards (Peacock, 1952), provide nutrition for the cartilage plates and the adjacent intervertebral disc during growth (Donisch & Trapp, 1971), and persist into the second decade of life (Böhmig, 1930). These are associated during childhood and adolescence with radially running grooves at the junction of the cartilage plates and bony vertebral body (Theiler, 1965). The cartilage plate is described as loosely cemented to the underlying bone by a calcareous layer presumably calcified cartilage (Donohue, 1939; Schmorl & Junghanns, 1959).

In the growing individual it is clearly distinguishable, in ordinary light microscopy, from the intervertebral disc, (Peacock, 1951; Walmsley, 1953) though Peacock describes the junction of anulus and cartilage plate as a transitional zone, and Franceschini's (1947) polarised light studies show the continuity of the lamellar structure of the peripheral anulus into the horizontally oriented 'cartilage layer'. The 'cartilage layer' is said to contribute to the 'interstitial growth' of the anulus, a growth possibly induced by the vascular canals in the cartilage (Donisch & Trapp, 1971). During the rapid phase of growth of the nucleus pulposus in the foetus and infant the 'cartilage layer' is said to be eroded by the expanding nucleus, (Peacock, 1951; Walmsley, 1953), and the cartilage plate is said to be thicker during the first years of life than at later stages (Schmorl & Junghanns, 1959; Donisch & Trapp, 1971).

b) <u>Formation of the Ring Epiphysis</u>

Before adolescence, foci of calcification appear in the peripheral parts of the 'cartilage layer' which ossify to form a bony ring (Schmorl, 1928) known by some authors as an apophysis (Bick & Copel, 1950). R. Hanson (1926) reviewed the nineteenth century literature on the 'vertebral epiphyses' which were said to appear during adolescence. Hanson (1926) found that their earliest appearance was in a girl of 6 years. The foci of calcification are usually taken to appear at 6 - 8 years in girls and 7 - 9 years in boys. Ossification follows immediately, and proceeds to fusion with the vertebral body from 18 to 25 years. The central part of the 'layer' remains cartilaginous throughout life, bounding and separating the vertebral spongiosa and the nucleus pulposus, and is said to permit nutrition of the avascular nucleus from the vascular spongiosa (Gray, 1967).

c) Defects in the Cartilage Plate

Böhmig (1930) describes a funnel shaped defect or identation into the 'cartilage layer' at the junction of the nucleus pulposus with the situation of the former notochordal track through the vertebra. This funnel shaped defect, seen in median sagittal sections, is continuous at its apex with a translucent cell free area of matrix in the cartilage plate along the line of the former notochordal track. These features are described from foetal life onwards, persisting up to 20 or 25 years, and with the scars of former blood vessels may constitute weak points in the cartilage plates through which herniations from the nucleus into the vertebral spongiosa may occur (Böhmig, 1930). Such herniations, known as Schmorl's nodes, occur in 36% of adult vertebral columns (Schmorl and Junghanns, 1959).

F. NUTRITION OF THE INTERVERTEBRAL DISCS

Nutrition of the intervertebral disc during growth and development may be derived from two sources:- a) indirectly from vertebral blood vessels ramifying close to the intervertebral disc in the cartilage plates, and b) directly by blood vessels entering the periphery of the anulus fibrosus.

a) Vertebral sources:

A consideration of the vertebral blood supply is germane to the question of nutrition of the intervertebral disc. 1) An anastomotic network is formed in the vertebral canal on the dorsal aspect of the vertebral bodies from arteries entering the intervertebral foramina. A large branch from this network enters the centre of the dorsal surface of each vertebral body in the midline. (Harris & Jones, 1956; Wiley & Trueta, 1959; Somogyi, 1964; Mineiro, 1965). This 'primary' artery (Somogyi) branches out to all parts of the vertebral body, particularly to the cranial and caudal metaphyses. (Böhmig, 1930).

2) A series of smaller blood vessels ramify within the periosteum of the anterior and lateral surfaces of the 'waist' of the vertebra. Branches from this plexus termed 'secondary blood vessels' (Somogyi, 1964) arch radially around the caudal and cephalic surfaces of the centrum into the cartilage plates, and give off side branches in the direction of the intervertebral discs. These usually end close to the discs in capillary plexuses or "glomeruli" (Böhmig, 1930; Ehrenhalf, 1943; Somogyi, 1964; Mineiro, 1965;

Donisch & Trapp, 1971). Anastomotic arcades may also be formed with other vessels passing through the metaphysis from the centrum (Ehrenhaft, 1943). Böhmig (1930) describes vessels passing close to all parts of the disc including the nucleus pulposus. Donisch & Trapp (1971) state that the vessels are mainly confined to the peripheral (circumferential) part of the cartilage plate, and end close to the anulus fibrosus. Such vessels arching from the antero-lateral surface at the bone-cartilage junction are responsible for the "toothed appearance" of the immature caudal and cephalic vertebral end-surfaces (Theiler, 1965). With the advance of the ossification front, these vessels may disappear or become included in the bony centrum (Donisch & Trapp, 1971).

Experiments in immature rabbits, tracing the diffusion of fluorochrome into the intervertebral discs of animals sacrificed at given intervals after intravenous injection, have shown that the blood vessels of the cartilage plate play an important rôle in the nutrition of the developing disc, since diffusion takes place from the cartilage plate to the disc (Brodin, 1955). Walmsley (1953) and standard anatomical texts state that nutrients diffuse through the cartilage plate to the disc in both immature and adult humans. However, the blood vessels of the human cartilage plate gradually disappear during growth and finally disappear by about 25 years (Uebermuth, 1929; Bohmig, 1930). In the adult, very few blood vessels from the spongiosa perforate the calcified cartilage layer binding the cartilage plate to the bony vertebra (Stockwell, 1972), and Maroudas (1972) has shown that the calcified cartilage forms a significant barrier to diffusion. Ehrenhaft (1943) linked the disappearance of blood vessels from the cartilage plate to the onset of 'degenerative changes' in the third decade of life. In childhood and adolescence the sites of the original blood vessels are occupied by plugs of soft fibrocartilage (Böhmig, 1930; Schwabe, 1933). Deformations or "outpouchings" of the nuclei pulposi of children are described opposite the sites of these 'cartilage degeneration zones'. Hence these may be weak points in the cartilage plates through which herniations may pass subsequently forming Schmorl's nodes (Böhmig, 1930; Schwabe, 1933; Schmorl & Junghanns, 1959).

b) <u>Blood vessels in the Anulus Fibrosus</u>:

Small blood vessels in the anulus fibrosus were first described by Luschka (1858). Such vessels are found in the outer anulus of foetuses infants and children. Tondury (1958) describes their appearance in a 70mm. embryo. Ferguson (1950) describes them as tiny capillaries and Peacock (1951) states that they are only found in the posterior anulus. Prader (1947b) and Somogyi (1964) consider that they are entirely separate from the blood vessels of the vertebral body and enter the outer surface of the anulus radially. The largest vessels in the foetus are found dorso-laterally (Somogyi, 1964). Mineiro (1965) describes many small blood vessels in the outer anulus fibrosus anastomosing with with vessels in the longitudinal ligaments. Only the outer fibrous part of the anulus is vascular and a few small blood vessels persist in this peripheral part of the anulus in adults (Walmsley, 1953; Schellenberg, 1955 - cited by Somogyi, 1964; Malinski & Jelinek, 1955 - cited by But, 1959). Although Böhmig (1930) describes small blood vessels in the prenatal nucleus pulposus his illustration of them is far from convincing, and it is generally stressed that the nucleus is always devoid of blood vessels (Keyes & Compere, 1932; Peacock, 1952; Walmsley, 1953). The nucleus can therefore only be nourished by diffusion from the surrounding tissues. It has recently been suggested that diffusion from the anulus is more likely to be effective in the nutrition of central parts of the adult intervertebral disc than diffusion through the cartilage plate, since the diffusion rate through the anulus is comparable to that through articular cartilage, while diffusion through the cartilage plate from the vertebral spongiosa is hindered by the calcified cartilage layer joining them (Maroudas, 1972).

G. GROWTH OF THE VERTEBRAL COLUMN

(a) Dimensions of the Adult Vertebral Column

The average length of the normal adult vertebral column is said to be 70 cm. in males and 60 cm. in females (Gray, 1967; Cunningham, 1972). The intervertebral discs are variously stated to contribute one third, one quarter or one fifth of the presacral length of this column (Luschka, 1858; Poirier and Prenant, 1896; Paturet, 1951; Virgin, 1951; Schmorl and Junghanns, 1959; Gray, 1967; Cunningham, 1972).

In absolute terms the lowest lumbar discs are thickest (about 12 mm.) and the upper thoracic discs are thinnest (about 4 mm.). Relative to the height of the neighbouring vertebral bodies, the cervical and lumbar discs are thicker than the thoracic discs. In this sense, lower cervical and lower lumbar discs are the thickest discs (De Palma and Rothman, 1970; Cunningham, 1972).

(b) Dimensions of Individual Adult Vertebrae and Discs

Dimensions of individual vertebrae and discs are recorded by Poirier and Prenant (1896), Jacobi (1927), Todd and Pyle (1928), Jonck (1961), Nachemson & Morris (1964), Hurxthal (1968), Brandner (1972), Plaue (1972) and Farfan et al (1972). The dimensions or data given by the different investigators seldom correspond either as to their material or method of measurement. Poirier and Prenant (1896), recorded the vertical dimensions of some of the vertebrae and discs from three adults. Todd and Pyle (1928) measured the anterior and posterior vertical dimensions of all vertebral bodies and discs in a large series of Americans of different races, relating the data to vertebral column curvatures and race. Jacobi

Jacobi (1927) measured anterior, posterior and 'mid-centrum' heights of vertebral bodies and discs but confined his observations to the thoracic and lumbar regions. Hürxthal, as recently as 1968, felt it necessary to establish radiological norms for the heights of female lumbar vertebral bodies and discs.

A number of authors record their data as indices or areas, without publishing the dimensions from which the indices or areas are derived. Brandner (1972) determines normal adult values for two indices, (i) the ratio of the vertical diameter of the vertebral body to its sagittal diameter ("I-vb."), and (ii) the ratio of the minimum disc height to the maximum vertebral body height (of the adjacent vertebra), ("I-d".). He records these indices for vertebrae and discs from T 12 to L 3. Plaue (1972) compares the sagittal and coronal diameters of thoracic and lumbar vertebral bodies and relates them to the cross-sectional area of the vertebral bodies, presenting his data as indices and ratios. Nachemson and Morris (1964) calculate the transverse-sectional area of the disc L 3-4 in adults from coronal and sagittal diameters, in order to deduce forces acting per unit area in each disc. Farfan et al (1972) make horizontal measurements on lower lumbar discs in an attempt to correlate the shape of the disc to the pattern of disc degeneration. They record only the ratio of coronal diameter/sagittal diameter for each disc.

(c) Dimensions of Immature Vertebrae and Discs

(i) Normal: Relatively few studies publish measurements on immature vertebral columns, and again the dimensions measured do not often correspond. Aeby (1879) measures and compares the dimensions of different regions of the vertebral column at various stages of development. His main thesis involves comparisons between newborn and adult vertebral columns. He records dimensions from five vertebral columns between birth and sixteen years. Ballantyne (1892) measures the length of cervical thoracic and lumbar regions of the newborn vertebral column, and expresses these as a percentage of the length of the whole column. Lippert and Lippert (1960) measure the vertical coronal and sagittal dimensions of all vertebral bodies (cartilaginous) in eighty fetuses from 9 - 35 cm. C.R.L. and studies their allometric growth. They do not give disc dimensions. Knutsson (1961) measures the coronal and sagittal diameters of the first lumbar vertebra in 175 radiographs of children. Brandner (1970) studies the 'I-vb' and 'I-d' for T 12 to L 3, calculated from measurements on 187 radiographs of children (from birth to adolescence).

(ii) Abnormal: Hipps (1961) studies the effects of prolonged recumbency, due to poliomyelitis, on the shape and dimensions of the vertebral bodies in children. Rabinowitz and Moseley (1964) study the altered shape of lumbar vertebrae in Down's syndrome. Houston and Zaleski (1967) examine differences in the 'vertebral body index' ('I-vb' of Brandner) in mentally retarded children graded according to physical activity, drawing the conclusion that inactivity increases vertical vertebral growth. With the exception of Aeby (1879) who records external vertical dimensions of discs from a very small number of cases, no record of the vertical or horizontal dimensions of immature discs at different stages of development can be found in the literature.

(d) Growth of the Vertebral Column and of Vertebrae

Mau (cited by Hanson, 1926), Risser (1936); Calvo (1957); Roaf (1960); Anderson (1965) and Nelson et al (1969), give general accounts of the rates of growth of the normal vertebral column at different ages. The vertebral column is said to grow rapidly in height until six years and more slowly from six to ten years in girls and until twelve years in boys, when the adolescent growth spurt occurs lasting until 15 years in girls and 17 years in boys. Mau (cited by Schmorl and Junghanns, 1959) also states that the farther caudad a vertebra is situated the greater its growth in height and breadth. Aeby (1879), Ballantyne (1892) and Lippert and Lippert (1960) state that the cervical region of the vertebral column forms a relatively greater proportion of the total vertebral column length during the early stages of development, and that the lumbar and sacral regions grow more rapidly than the other regions at later stages of development.

Vertical growth of the vertebrae takes place in the growth plates and metaphyses at the cranial and caudal ends of each vertebral body (Harris, 1933; Bick and Copel, 1950; Schinz et al, 1952; Schmorl and Junghanns, 1959). The ring epiphyses (which appear at 8 - 10 years and fuse at about 20 years) are not surrounded by cartilage growth plates, and are said not to contribute to growth (vertical) of the vertebra (Bick and Copel, 1950). Horizontal growth of the vertebral body is appositional (after horizontal extension of the centrum to the periphery of the cartilage model).

This growth is described as taking place principally or entirely at the anterior and lateral surface of the vertebral body (Siegling, 1941; Knutsson, 1961; Larsen and Nordentoft, 1962; O'Brien, 1969; Katzman, 1969), but Reichmann and Lewin (1972) describe histological evidence of growth at the posterior surface of the lumbar vertebral bodies in children under twelve years.

Accounts of development of the intervertebral disc (already reviewed) pay little attention to its growth, making no attempt to measure the changes in disc dimensions, and confining themselves to observation of histological changes.

MATERIALS AND METHODS

1. POST-MORTEM MATERIAL

Material was listed in order of ascending maturity.

A. SOURCES

1. Seven serially sectioned embryos (numbered E 1 to E 7) from the collection kept at the Department of Anatomy, University of Edinburgh.

2. Vertebrae and discs from the cervical, thoracic and lumbar regions of sixty foetuses, infants and children (numbered 1 to 60 - Table 1).

Material from the two youngest foetuses (specimens 1 and 2) was obtained post-operatively at termination of pregnancy, fixed by glutaraldehyde injection and post-fixed in 10% formalin for two days.

Material from specimens 3 to 60 was obtained at autopsy, usually within 24 hours of death. The age of each individual and the cause of death were noted. In all specimens the external appearance of the vertebral column was normal and there was no apparent skeletal anomaly.

Blocks of tissue including vertebral bodies and intervening intervertebral discs, from lower cervical, mid-thoracic, and lumbar regions were removed by cutting through the pedicles (and necks of ribs where necessary) and horizontally either through the disc or vertebral body above and below the specimen. The blocks were fixed in 10% formalin for varying periods from two to fourteen days.

B. SECTIONING OF MATERIAL

Material from specimens 1 to 60 was treated in one of three ways.

1. Preparation of Thick Sections of Undecalcified Material

Forty-four blocks of tissue from 17 individuals were dehydrated in graded alcohols, embedded in low viscocity nitrocellulose ('L.V.N'), and sectioned by a thin diamond-impregnated disc rotating at 6000 r.p.m. on a precision lathe (only blocks under 2cm. by 2cm. could be sectioned by this method). For each cut the block was advanced by 20,25 or 30 thousandths of an inch. Most sections were approximately 200/u thick using a block advance of 0.020" (since about 300/u thickness was lost in cutting). Sections were lightly stained with haematoxylin (Delafield) and light green and mounted in Canada balsam.

2. Preparation of Thick Sections of Decalcified Material

Seventy-four blocks from 46 individuals (Table 1) were decalcified in formic acid citrate solution (equal volumes of 50% formic acid and 20% sodium citrate) with daily changes for from two to ten days depending on the size of the block. They were then dehydrated, embedded in 'L.V.N.' and sectioned with a microtome at 150 or 200/u. Serial sections were stained and mounted from the smaller blocks of tissue, but only one in three or one in four sections was stained and mounted from the larger blocks. All sections were stained with haematoxylin (Delafield) and light green and mounted in Canada balsam.

3. Preparation of Thin Sections of Decalcified Material

Ten blocks from six individuals (Table 1) were decalcified, dehydrated and double embedded in paraffin wax. Sections were cut at 10 or 15/u, stained with haematoxylin and eosin and mounted in Canada balsam. A few 50/u L.V.N. embedded sagittal sections were cut near the midline from a number of blocks.

Table 1 lists the age, sex and cause of death of each individual, and shows the method of embedding and the plane and thickness of section. The age and cause of death were ascertained from the pathologist's report (Nos. 3-60). With two exceptions the cause of death had no direct relevance to anomalies of the vertebral column. In Nos. 22 and 42 slight degrees of hydrocephalus were reported. No. 42 also showed localised upper sacral spina bifida occulta. Histological examination of discs and vertebral bodies from these two cases showed no anomalies, and their appearance and dimensions conformed with those of specimens of comparable maturity. Therefore they were not excluded from the study. No. 18 and No. 47 were excluded from the study of growth by measurement since No. 18 showed marked irregularities of shape in some bony vertebral bodies, and No. 47 showed a marked degree of physical retardation.

Tables 2a and 2b summarise the information contained in Table 1.

TABLE 1(a)

Embryos and Fetuses

KEY: D = Decalcified, U = Undecalcified; C = Cervical, T = Thoracic, L = Lumbar; M.L. = Mid-line of Vertebral Column, L.V.N. = Low Viscosity Nitrocellulose

* denotes photograph or tracing of single horizontal section through fresh disc
\+ denotes remaining half disc

Case Number	Sex	Maturity	Cause of Death	Specimen	D or U	Embedding Medium	Plane of Section	Thickness of Section in Microne	Sections Mounted
E 1	-	20mm.		Whole Embryo	-	Wax	Sagittal	10	Serial
E 2	-	20mm.		"	-	"	"	"	"
E 3	-	25mm.		"	-	"	"	"	"
E 4	-	(a) 28mm.		"	-	"	"	15	"
		(b) 28mm.		"	-	"	Horizontal	"	"
E 5	-	30mm.		"	-	"	Sagittal	10	"
E 6	-	75mm.		"	-	"	"	20	Appr. 1 in 30
E 7	-	23w.180mm.		"	-	"	Horizontal	"	Appr. 1 in 20
1	-	18w.115mm.		Cervical	D	"	Sagittal	"	Serial
				Thoracic	D	"	"	"	"
				Lumbar	D	"	"	"	"
2	-	22w.167mm.		Cervical	D	"	"	"	"
				Thoracic	D	"	"	"	"
				Lumbar	D	"	"	"	"
3	F	25w.	Prematurity	C 5 - 7	D	L.V.N.	"	150	"
				L 3 - 5	D	"	"	"	"
				L 2 - 3	D	Wax	"	10	ML only
4	F	29w.	Pneumonia	C 5 - 7	U	L.V.N.	"	200	To M.L.
				T 8 -10	U	"	"	"	"
				L 3 - 5	U	"	"	"	"
5	F	30w.	Cerebral Haemorrhage	L 3 - 4	D	"	"	150	1 in 2 to M.L.
				L 4 - 5	-	-	Horizontal	*photograph	-
6	M	30w.	Septicaemia	C 5 - 7	U	L.V.N.	Sagittal	200	To M.L.
				T 8 - 9	U	"	"	"	"
				T 9 -10	U	"	Horizontal	"	Serial
				L 3 - 4	U	"	Sagittal	"	To M.L.
				L 4 - 5	U	"	Coronal	"	Serial
7	M	30w.	Hyaline Membrane	C 5 - 7	U	"	Sagittal	"	To M.L.
				T 8 -10	U	"	"	"	"
				L 2 - 5	U	"	"	"	"
8	M	30w.	Prematurity	L 2 - 3	D	"	"	150	1 in 3 to M.L.
				L 3 - 4	D	"	Coronal	"	Serial
				L 4 - 5	D	"	Horizontal	"	"
9	M	31w.	Cerebral Haemorrhage	L 3 - 4	D	"	Sagittal		1 in 3 to M.L.
				L 4 - 5	-	-	Horizontal	*photograph	
10	F	32w.	Anoxia	L 3 - 4	D	L.V.N.	Sagittal	200	Serial to M.L.
11	F	32w.	Cerebral Haemorrhage	L 3 - 4	D	"	"	"	1 in 2 to M.L.
12	M	33w.	Accidental Haemorrhage (Maternal)	C 6 - 7	D	"	Horizontal	200	Serial
				L 3 - 5	U	"	Sagittal	"	To M.L.
13	M	33-34w.	"	L 3 - 4	D	"	"	"	1 in 2 to M.L.
14	M	34w.	Respiratory failure	C 4 - 7	U	"	"	"	To M.L.
				T 8 -10	U	"	"	"	"
				L 3 - 5	U	"	"	"	"
15	F	34w.	Oesophageal Atresia	L 3 - 4	D	L.V.N.	"	"	1 in 2 to M.L.
				L 4 - 5	-	-	Horizontal	*photograph	
16	F	35w.	Hyaline Membrane Disease	C 6 -T1	U	L.V.N.	Sagittal	200	To M.L.
				T 8 - 9	U	"	"	"	"
				L 3 - 4	U	"	Horizontal	"	Serial
				L 4 - 5	U	"	Sagittal	"	To M.L.
17	M	35w.	"	C 6 - 7	U	"	"	"	"
				T 8 -10	U	"	"	"	Complete
				L 3 - 5	D	"	"	150	1 in 2 to M.L.
18	-	36w.	Congenital Heart Dis.	L 1 - 5	D	"	"	200	Serial to M.L.
19	M	36w.	Accidental Haemorrhage (Maternal)	T12-L5	D	"	"	150	1 in 3 to M.L.

TABLE 1(b)

Newborn

KEY: D = Decalcified C = Cervical M.L. = Mid-line of Vertebral Column
U = Undecalcified T = Thoracic L.V.N. = Low Viscosity Nitrocellulose
L = Lumbar

* denotes photograph or tracing of single horizontal section through fresh disc
\+ denotes remaining half disc

Case Number	Sex	Maturity	Cause of Death	Specimen	D or U	Embedding Medium	Plane of Section	Thickness of Section in Microne	Sections Mounted
20	F	40w.	Anoxia	C 5 - 7	U	L.V.N.	Sagittal	200	To M.L.
				T 8 - 9	U	"	"	"	"
				L 3 - 5	U	"	"	"	"
21	F	38 - 40w.	Accidental haemorrhage (maternal)	C 5 - 7	U	"	"	"	"
				T 8 -10	U	"	"	"	"
				L 3 - 5	U	"	"	"	"
22	M	40w.	Cerebral haemorrhage	C 5 - 7	U	"	"	"	"
				T 8 -10	U	"	"	"	"
				L 3 - 5	U	"	"	"	"
23	F	40w.	Congenital heart disease	C 5 - 7	U	"	"	"	"
				T 8 -10	U	"	"	"	"
				L 3 - 5	U	"	"	"	"
24	M	40w.	Intrauterine infection	C 5 - 7	D	"	"	"	1 in 3 to M.L.
				T 6 - 9	D	"	"	"	1 in 3 to M.L.
25	F	40w.	Meningitis	C5 - T1	D	"	"	"	1 in 3 to M.L.
				T 7 - 9	D	"	"	"	1 in 4 to M.L.
				L 4 - 5	D	"	"	"	1 in 4 to M.L.
26	F	40w.	Fallot's Tetralogy	L 2 - 3	U	"	Horizontal	"	Serial
				L 4 - 5	U	"	Sagittal	"	To M.L.
27	M	40w.	Coarctation of aorta	L 2 - 3	D	"	Horizontal	150	1 in 2
				L 3 - 4	D	"	Sagittal	"	1 in 3 to M.L.
				L 4 - 5	U	"	"	200	To M.L.
28	F	40w.	Cerebral haemorrhage	L 4 - 5	D	"	"	150	1 in 3 to M.L.
29	M	40w.	Diaphragm. Hernia Post-operative death	L 3 - 4	U	"	"	200	To M.L.
				L 4 - 5	D	"	"	150	1 in 3 to M.L.
30	M	40w.	No anomoly found	L 3 - 4	D	"	Coronal	"	1 in 4
				L 4 - 5	D	"	Sagittal	200	1 in 5 to M.L.
31	M	40w.	" "	L 3 - 4	D	"	Coronal	150	1 in 4
32	M	40w.	Congenital heart dis.	L 3 - 4	D	"	Sagittal	"	1 in 5 to M.L.
33	F	40w.	Anoxia	L 1 - 5	D	"	"	200	1 in 5 to M.L.
34	M	40w.	No anomoly found	L 3 - 4	D	"	"	"	1 in 2 to M.L.
35	F	40w.	Congenital heart dis.	L 3 - 4	D	"	"	200	Serial to M.L.
				L 4 - 5	-	-	Horizontal	*photograph	

TABLE 1(c)

Infants and Children

KEY: D = Decalcified C = Cervical M.L. = Mid-line of Vertebral Column
U = Undecalcified T = Thoracic L.V.N. = Low Viscosity Nitrocellulose
L = Lumbar

* denotes photograph or tracing of single horizontal section through fresh disc
\+ denotes remaining half disc

Case Number	Sex	Maturity	Cause of Death	Specimen	D or U	Embedding Medium	Plane of Section	Thickness of Section in Microns	Sections Mounted
36	F	1 month	Cerebral haemorrhage	L 4 - 5	D	Wax	Sagittal	15	Serial incomplete
37	M	1 "	Gastro-enteritis	C 5 - 7	U	L.V.N.	"	200	To M.L.
				T 8 -10	U	"	"	"	"
				L 3 - 5	U	"	"	"	"
38	M	2 "	Congenital heart disease	L 3 - 4	D	"	"	"	Serial to M.L.
39	M	3 "	Fallot's Tetralogy	L 2 - 3	D	"	Horizontal	150	Serial
				L 3 - 5	D	"	Sagittal	"	1 in 5 to M.L.
40	M	3½ "	Acute respiratory infection	T 7 - 9	D	"	"	200	1 in 5 to M.L.
				L 4 - 5	D	"	"	"	1 in 5 to M.L.
				L 4 - 5+	D	"	Horizontal	"	Serial
41	M	4 "	Septicaemia	L 3 - 4	D	Wax	"	10	"
				L 4 - 5	D	L.V.N.	Sagittal	150	1 in 5 to M.L.
42	M	4½ "	Spina bifida & hydrocephalus; meningitis	T 8 - 9	D	"	"	"	3 in 6 to M.L.
				L 3 - 4	D	"	Horizontal	"	1 in 4 to M.L.
				L 4 - 5	D	"	Sagittal	"	1 in 4 to M.L.
43	M	5 "	Gastro-enteritis	C 5 - 7	U	L.V.N.	"	200	To M.L.
				T 8 - 9	U	"	"	"	"
				T 9 -10	U	"	Coronal	"	Complete
				L 3 - 5	U	"	Sagittal	"	To M.L.
44	M	6 "	Mitral atresia (physically retarded)	L 1 - 5	D	"	"	"	1 in 5 to M.L.
45	F	10 "	Biliary atresia	L 3 - 4	D	"	"	"	1 in 5 to M.L.
				L 4 - 5	-	-	Horizontal	*photograph	
46	M	1yr. 2m.	Measles broncho-pneumonia	C 5 - 7	D	L.V.N.	Sagittal	150	1 in 4 to M.L.
				C 5 - 7+	D	"	Coronal	"	1 in 3 to M.L.
				T 8 -10	D	"	Sagittal	"	1 in 2 to M.L.
				L 4 - 5	D	"	"	"	1 in 2 to M.L.
47	F	1yr. 6m.	Broncho-pneumonia mentally & physically retarded	L 2 - 3	D	"	Horizontal	200	1 in 2
				L 3 - 4	D	"	Coronal	"	1 in 5
				L 4 - 5	D	"	Sagittal	150	1 in 2 to M.L.
48	F	1yr. 8m.	Myocarditis - heart failure	L 3 - 4	D	"	Horizontal	"	Serial
				L 4 - 5	D	"	Sagittal	"	1 in 5 to M.L.
49	M	2 yrs.	Biliary atresia - cirrhosis	L 4 - 5	D	"	"	"	1 in 4 to M.L.
50	F	2 yrs.	Nephro-blastoma	L 2 - 3	D	"	Horizontal	"	Serial
				L 4 - 5	D	"	Sagittal	"	1 in 5 to M.L.
51	M	2yr. 3m.	Tracheo-oesoph. fistula	L 4 - 5	D	"	"	"	1 in 4 to M.L.

TABLE 1(c) - continued

Case Number	Sex	Maturity	Cause of Death	Specimen	D or U	Embedding Medium	Plane of Section	Thickness of Section in Microns	Sections Mounted
52	F	2yr. 8m.	Broncho-pneumonia	T 8 - 9	D	L.V.N.	Sagittal	200	1 in 4 to M.L.
				L 4 - 5	D	"	"	"	1 in 4 to M.L.
53	F	3 years	Metachromatic leucodystrophy	L 3 - 4	D	"	Horizontal	"	2 sections
				L 4 - 5	D	"	Sagittal	150	1 in 2 to M.L.
54	F	3yr. 4m.	Leucaemia	C 6 - 7	D	"	Coronal	"	1 in 2
				T 8 - 9	D	"	Sagittal	"	1 in 2 to M.L.
				L 4 - 5	D	"	Horizontal	"	1 in 2
55	M	3yr. 9m.	Febrile convulsions and inhalation of gastric contents	C 6 - 7	U	"	Sagittal	200	To M.L.
				T 8 - 9	D	"	"	150	1 in 2 to M.L.
				T 7 - 8	D	"	Horizontal	100	16 section
				L 4 - 5	D	"	Sagittal	150	1 in 3 to M.L.
56	M	4 years	Broncho-pneumonia	L 3 - 4	D	"	"	200	1 in 5 to M.L.
				L 4 - 5	-	-	Horizontal	*tracing of projection	
57	M	4yr. 9m.	Leucaemia	T 8 - 9	D	L.V.N.	Sagittal	200	1 in 5 to M.L.
				L 3 - 4	D	"	Horizontal	"	1 in 2
				L 4 - 5	D	"	Sagittal	"	1 in 5 to M.L.
58	M	5 years	Leucaemia	L 2 - 3	D	"	Horizontal	"	1 in 2
				L 3 - 4	D	Wax	Sagittal	10	120 sect.
				L 4 - 5	D	L.V.N.	"	200	1 in 5 to M.L.
59	F	$7\frac{1}{2}$ years	Aspiration pneumonia	T 7 - 9	D	"	"	"	1 in 5 to M.L.
				L 4 - 5	D	"	"	"	1 in 5 to M.L.
60	M	10 years	Phaeochromocytoma cardiac arrest	L 4 - 5	D	"	"	150	1 in 4 to M.L.
				L 5 -S1	-	-	Horizontal	*tracing of projection	

TABLE 2(a)

Summary of Blocks of Tissue Sectioned

I: Age Range
II: (a) Region: (b) Plane of Section

KEY: S.S. = Sagittal section; C.S. = Coronal section
A. = Serial sections; T.S. = Transverse or Horizontal section
B. = A single Horizontal section through a fresh disc

I	II									
AGE GROUP	LUMBAR REGION				THORACIC REGION			CERVICAL REGION		
	S.S.	C.S.	T.S. A	T.S. B	S.S.	C.S.	T.S.	S.S.	C.S.	T.S.
"Embryos" (8-18w.)	7	-	-	-	7	-	-	7	-	-
"Foetuses" (20-36w.)	18	2	3	2	7	-	2	9	-	2
"Newborn"	15	2	2	1	7	-	-	7	-	-
"Infants" (2-12m.)	8	-	4	1	3	1	-	1	-	-
Second & Third Years	7	-	3	-	2	-	-	1	1	-
Fourth & Fifth Years	5	-	4	1	3	-	1	1	1	-
Five to Ten Years	3	-	1	1	1	-	-	-	-	-
TOTALS	63	4	17	6	30	1	3	26	2	2

TABLE 2(b)

Summary of Discs sectioned - by (a) Age: (b) Region

Disc	Numbers of Discs Sectioned						
	"Embryos" (8-18 weeks)	"Foetuses" (20-36 weeks)	"Newborn"	"First year" (2-12 months)	1 - 3 yrs.	3 - 5 yrs.	5 - 10 yrs.
C4-5	7	2	0	0	0	0	0
C5-6	7	6	7	1	1	0	0
C6-7	7	9	7	1	1	2	0
T7-8	7	1	2	1	0	1	1
T8-9	7	7	7	3	2	3	1
T9-10	7	6	4	1	1	0	0
L1-2	7	3	1	1	0	0	0
L2-3	7	6	3	2	2	0	1
L3-4	7	18	13	7	2	3	1
L4-5	7	15	14	7	7	5	3
L5-S1	7	2	0	0	0	0	1
TOTALS	77	75	58	24	16	14	8

Cumulative total: 272 discs

C. EXAMINATION OF MATERIAL

1. Definitions and Nomenclature

One of the principal methods used in this study was measurement of the disc and its parts. Official nomenclature was inadequate for description of the parts of the growing disc measured. The terms used in this study (Text figs. 7-9) were as follows -

'Disc Proper' - This was the 'conventional' disc including the anulus fibrosus and the nucleus pulposus (Text fig. 8).

'Total Disc' - This included, with the 'Disc Proper', the cartilage plates bounding it rostrally and caudally, which cap the end surfaces of the adjacent 'bony vertebral body' (Text fig. 7).

Cartilage Plates - These terms were used as in the official nomenclature but two parts were differentiated (a) The 'cartilage columns'. Here the cells were arranged in columns vertical to the advancing ossification front of the vertebral body. (b) A layer of hyaline cartilage which separated the cartilage columns from the 'Disc Proper', (Text fig. 8). Here the flattened cells lie with their long axes horizontal.

'Notochordal Nucleus Pulposus' - The conventional nucleus pulposus, defined as the soft gelatinous central part of the disc (Cunningham 1972), was not a sufficiently clearly defined entity to enable measurement. The 'notochordal nucleus' consisted of clumps and strands of cells in a clear mucoid matrix. Thus defined, the 'notochordal nucleus' could be measured (Text fig. 9a).

'Anulus Fibrosus' - This was defined as the fibrous tissue and fibrocartilage surrounding the perimeter of the 'notochordal nucleus'. Its horizontal thickness was measured in the median sagittal plane to indicate the position of the 'notochordal nucleus' relative to the anterior and posterior surfaces of the disc. Two parts were distinguished: (a) the outer 'lamellar anulus' consisting of concentric lamellae of fibrous tissue and fibrocartilage, and (b) merging with it, the inner 'cellular fibrocartilage' which had no lamellar arrangement but corresponded to the 'inner cell zone' of Peacock (1951) (Text figs. 9a and b).

2. Method of Measurement

Linear measurements were made under a microscope at times 20 magnification using an 0.1mm. grid placed directly on the cover slip over the section. The discs measured were principally L 4-5, T 8-9 and C 5-6.

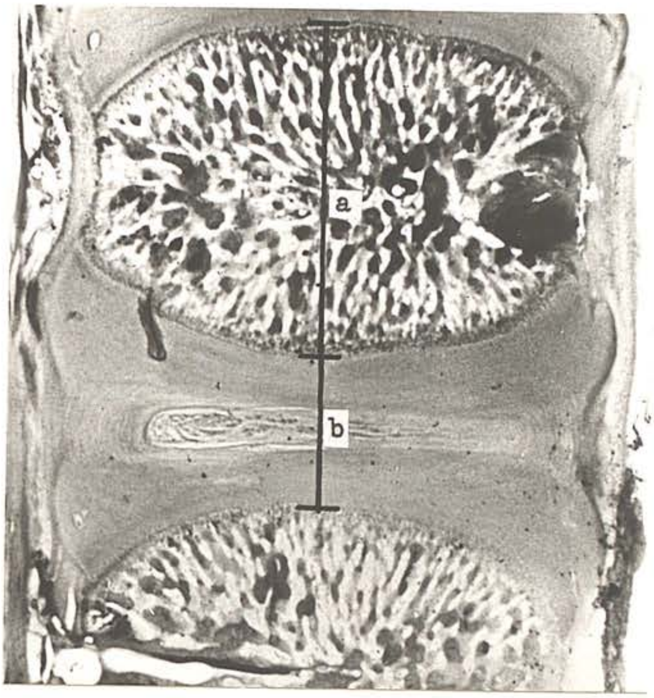
3. Vertical Measurements

(a) Height of 'vertebral body' and of 'total disc'. Each measurement was made midway between the anterior and posterior surfaces on a median sagittal section. The 'total disc' (b, Text fig. 7) was measured to the nearest 0.05mm, and was the distance between the two bony vertebral bodies. The 'vertebral body' height was this dimension of the bony vertebral body rostral to the disc being measured (a, Text fig. 7 and Tables 7 and 8).

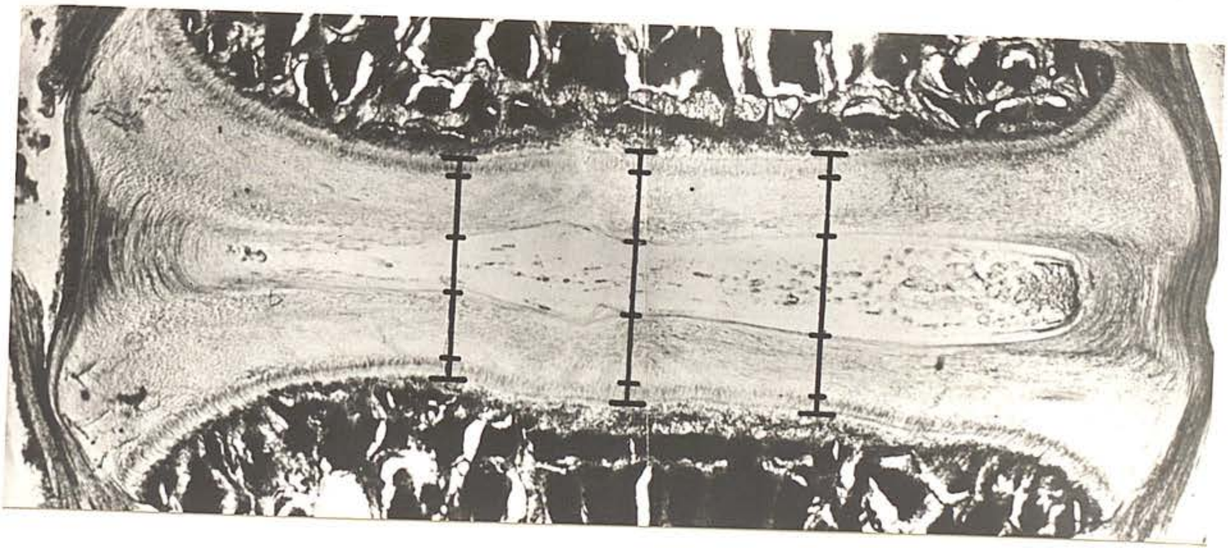
(b) 'Disc proper' and cartilage plates. The thicknesses or heights of each cartilage plate and of the 'disc proper' were

Text-fig. 7

Vertical Measurements



a = 'vertebral body' b = 'total disc'



Text-fig. 8

'Disc Proper','Cartilage Layer' & Cartilage Columns.

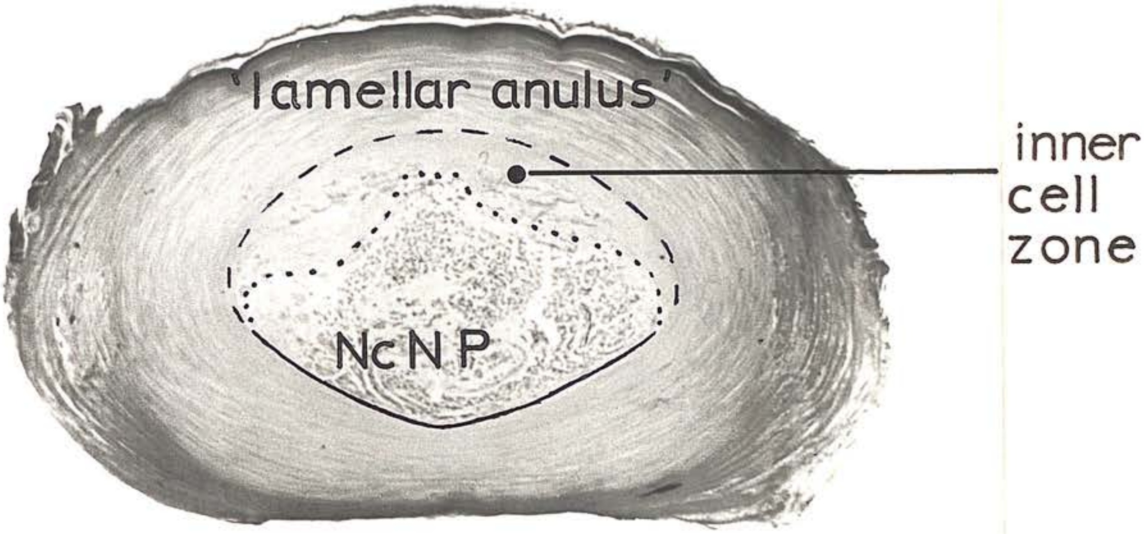
measured in the median plane at three points (Text fig. 8); (i) midway between the anterior and posterior borders of the disc; (ii) at the junction of the anterior and middle thirds of the disc; (iii) at the junction of the posterior and middle thirds of the disc. Three measurements were necessary in order to minimise the effect on one measurement of (a) local irregularity in the bony vertebral surface bounding the cartilage plate, and (b) variation in the position of the notochordal nucleus pulposus. The average thickness (height) of the central part of each cartilage plate was derived by calculating the mean of the three heights measured in each case. The average thickness of the central part of the 'disc proper' was calculated in the same way. In addition, the average thickness of the central part of the cartilage column layer was obtained by taking the same three measurements of this layer and calculating the mean. The results are listed in Table 9.

(c) Median Sagittal Outlines. To illustrate the changes in size and position of the various parts of the discs with age, outline tracings were made from median sagittal sections of discs at the various ages, projected at standard magnification.

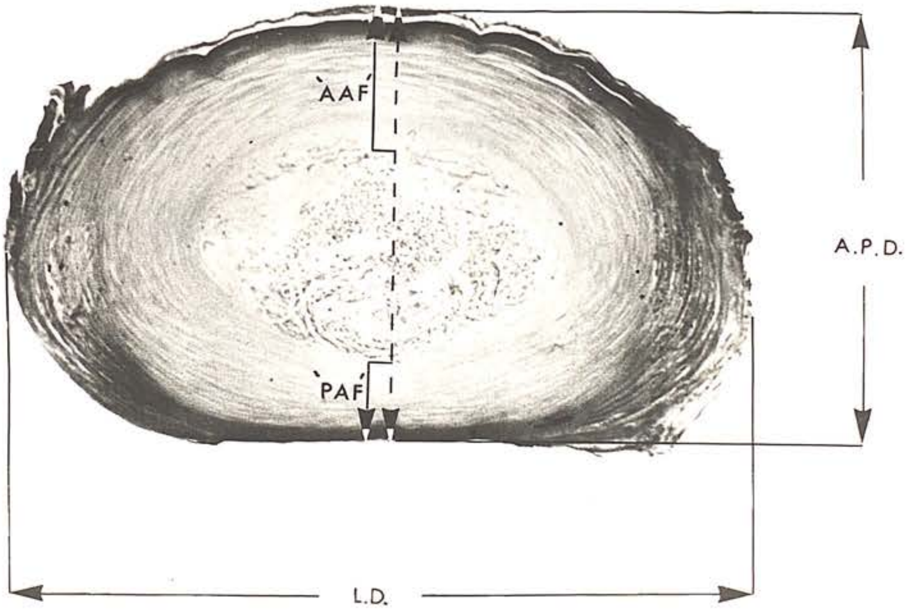
4. Horizontal Measurements

(a) Antero-Posterior and Lateral Diameters of the 'Disc Proper' and 'Notochordal Nucleus'. Thickness of the 'Anulus Fibrosus' (Text fig. 9b). These were measured and recorded to the nearest 0.05mm in all but the embryos where they were measured to the nearest 0.01mm. using an eyepiece grid at times 48 magnification (Table 10).

Text-fig. 9



(a)



(b)

The antero-posterior diameters of the disc and nucleus were measured in the median plane. The anterior and posterior 'anulus' (A.A.F. and P.A.F., Text-fig. 9b) were also measured in the median plane from the anterior and posterior margins of the disc to the respective anterior and posterior boundaries of the 'notochordal nucleus' and included the fibrocartilage* layer. These antero-posterior measurements were made directly on horizontal and median sagittal sections, and in coronally sectioned discs they were derived from the number of sections of known thickness for the whole disc and each part of it.

The lateral diameters were the maximum lateral diameters of the disc and nucleus, measured directly in horizontal and coronal sections.

In most cases, sagittal sections were cut from the lateral border to a point just beyond the midline of the disc. The lateral diameter of this sectioned half disc was derived from the known thickness of the sections and to this was added the lateral dimension of the unsectioned half block, measured to the nearest 0:1mm. with calipers, to obtain the total diameter. In some sagitally sectioned discs the unsectioned half block was not measured. In these cases the lateral dimensions of the disc and 'notochordal nucleus' were derived by doubling the distance from the midline of the disc to the lateral boundary of the disc and 'notochordal nucleus' respectively. The median sagittal section of the disc could be defined accurately since it was consistently found to contain (i) a large sagittal vein in the

(* i.e. 'inner cell zone')

vertebral body, and (ii) a small funnel-shaped depression from the nucleus pulposus into the cartilage plate, at the situation of the former notochord, (Text fig. 10). In a few cases the lateral dimensions of the disc and nucleus could not be accurately estimated as either the lateral border of the anulus or the funnel-shaped depression did not fall into one of the mounted sections. In these cases the horizontal dimensions of the disc were not recorded.

The horizontal dimensions of the disc and nucleus, so obtained, were tabulated in order of age. Cases of similar age were arranged in groups. For each age group the mean dimensions of the 'disc proper', 'notochordal nucleus' and 'anulus fibrosus' were calculated. (Table 10).

(b) <u>Horizontal Outline Reconstructions</u>.

i. Outlines of discs and notochordal nuclei were projected and traced from horizontal sections.

ii. Horizontal reconstructions of disc outline, and notochordal nucleus outline and position, were plotted from measurements made on sagittal sections at known intervals.

Projected outlines, and reconstructions were drawn to the same (x 4) scale, and were representative of all ages from 20 weeks gestation to 10 years (i.e. at least one such outline was available for each age group).

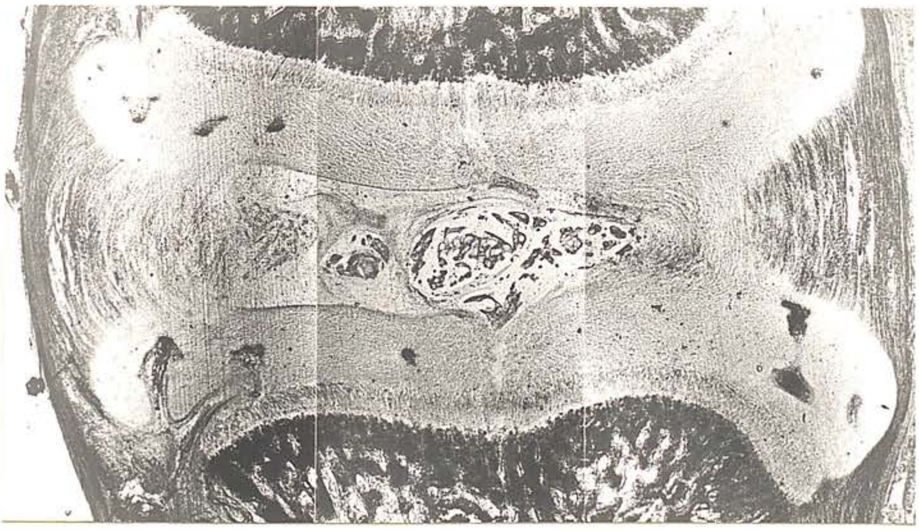
The outlines available for each age group were superimposed, and free hand outlines were drawn to represent the average shape

Text-fig. 10

Notochordal Defects in Cartilage Plates

Horizontal section through a fresh foetal lumbar disc

The dark oval area at the anterior end of the nucleus pulposus in the median plane is a funnel-shaped defect extending into the cartilage plate towards the bony vertebral body.



Median sagittal section of a foetal lumbar disc showing a triangular depression and linear clear cell free zone extending from the nucleus pulposus into the lower cartilage plate.

of the disc of the notochordal nucleus shape and position for this age. The mean horizontal dimensions of disc and nucleus for each age group tabulated as described were used to correct the dimensions of the free hand outline while maintaining as nearly as possible the shape of outline typical of that age. The same procedure was adopted to produce outlines typical of cervical thoracic and lumbar discs at different stages of growth from 20 weeks onwards.

(c) Anterior and Posterior Growth from the situation of the notochord.

i. In the Disc.. The 'average position' of the former notochord was determined for each age group by measuring the distances in a horizontal plane, from the anterior and posterior borders of the anulus to the 'notochordal remnants' in the cartilage plates, and calculating mean distances for each group. The 'position of the notochord' was marked as a dot on each 'average outline', and the outlines for all age groups (in a given region) were superimposed and traced, centred on this point. This indicated the anterior and posterior growth of the disc relative to the former notochord. (Text-figs. 45 and 47).

ii. In the Vertebral Body. In a number of cases, cartilage islands, believed to be in the position formerly occupied by the notochord (Taylor 1972), were seen in median sagittal sections near the centre of the bony vertebral body. By measuring from a vertical line through the centre of these islands to the anterior and posterior surfaces of the bony vertebral body midway between superior and inferior surfaces, anterior and posterior growth relative to these notochordal elements was estimated at different stages. Measurements to the anterior border included the thickness of the anterior longitudinal ligament, but measurements to the posterior border included the periosteum and did not include the posterior longitudinal ligament. Where the middle of the posterior surface of the vertebral body was perforated by a vein the measurement was made to a vertical line joining the boundaries of the orifice, (Table 11).

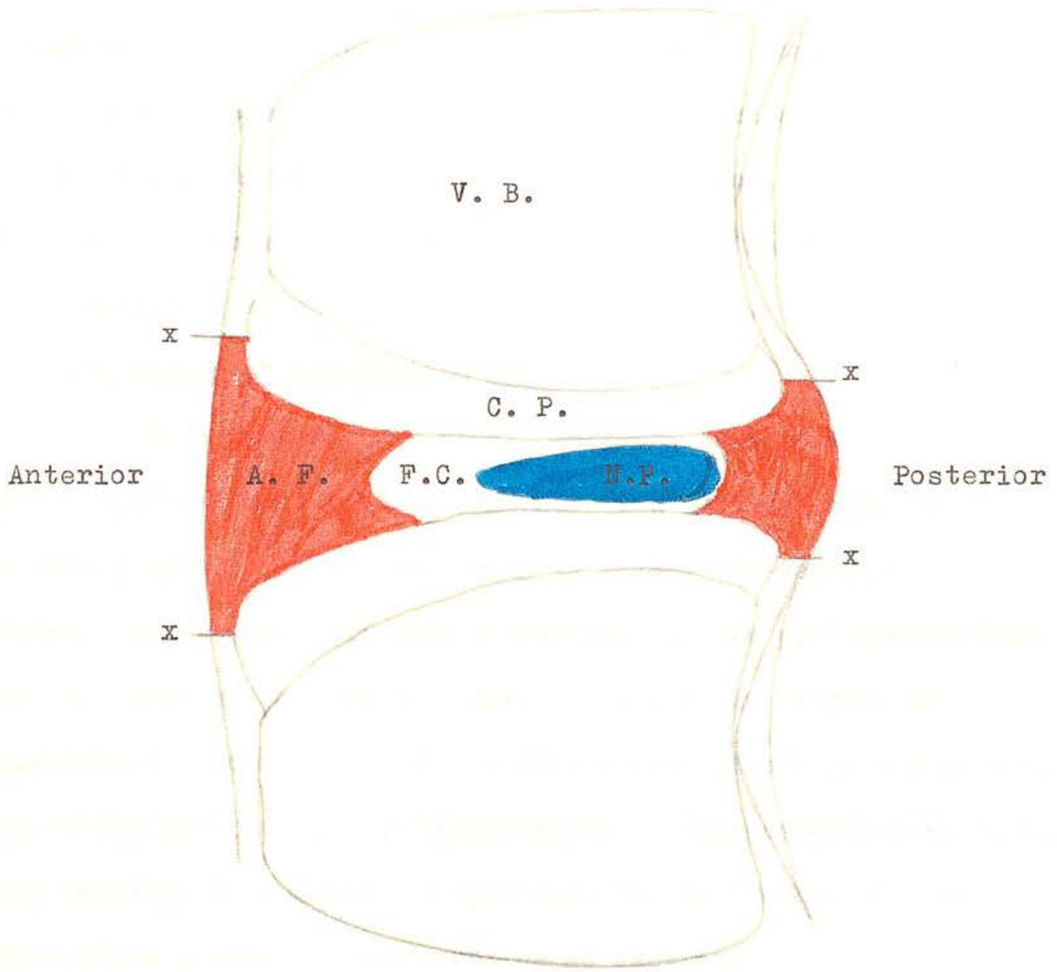
5. Volume Measurements

A complete series of sections from each of a representative series of discs (14 cervical, 13 thoracic and 25 lumbar discs) was projected at known magnification and tracings of the outlines of the notochordal nucleus were made. (Only one in two sections was used in the larger discs). The areas enclosed by these outlines were measured with a planimeter. Since the section thicknesses were known, the volume of the notochordal nucleus could be derived. In sagitally sectioned discs, the volume of the nucleus from its lateral border to the midline was estimated and this value was doubled, (Table 12).

Similar outlines of the 'disc proper' and the inner border of the lamellar anulus were projected and traced for 13 lumbar discs. The 'lamellar anulus' was arbitrarily defined as including the longitudinal ligaments, but limited by a horizontal line at the maximum anterior or posterior convexity of each adjacent cartilage plate (Text fig. 11). The inner border of the lamellar

Text Figure 11

Diagram Illustrating the Parts of a Newborn 'Disc Proper' as seen in Midline Sagittal Section.



The 'Disc Proper' includes
(a) 'Lamellar Anulus' - A.F. (red)
(b) 'Cellular Fibrocartilage'- F.C. (white)
(c) 'Notochordal Nucleus' - N.P. (blue)

x = arbitrary limits of anulus
(V.B. - 'Bony Vertebral Body', C.P. - Cartilage Plate).

The F.C. area is also referred to as the 'inner cell zone'.

anulus was taken as the inner limit of the concentrically oriented collagen fibres. Repeat tracings of the same sections gave considerable variations in estimated volumes of the 'lamellar anulus' and 'cellular fibrocartilage' components, particularly in the older discs, due to uncertainty as to their exact boundaries. Thus the results obtained could only be regarded as approximate for those regions of the disc. For this reason, attempts to measure the volume of the lamellar anulus and the cellular fibrocartilage regions were not pursued further.

6. Estimation of Contraction Artefact

In a part of this study, vertical measurements on post mortem material were grouped together with vertical measurements on radiographs. It was necessary to assess the degree of contraction artefact and make corrections in the post-mortem data for this part of the study. Also, in any study relying on measurements, it is important to assess the effects of the processing of the material on the measurements. Measurements were therefore recorded on a number of specimens in the fresh state, and again after processing and mounting as sections.

(a) Vertical and Horizontal Contraction. Thirteen blocks of fresh tissue were placed directly on x-ray plates, and lateral and antero-posterior x-rays were taken at a tube film distance of 4 feet. With small specimens of up to 50mm. length, at this long tube - film distance magnification error was insignificant. A needle was placed in the block before each x-ray, horizontally in the coronal plane for lateral x-rays, and horizontally in the sagittal plane for antero-posterior x-rays, so that the correct orientation of the x-ray beam could be checked on the radiograph. The vertical heights of the (undecalcified) bony vertebral bodies and the translucent disc spaces were measured midway between their anterior and posterior surfaces on the lateral radiographs. The horizontal diameters of the disc were measured on the antero-posterior and lateral radiographs when there were sufficiently clear soft tissue images. Similar measurements were repeated for the bony vertebral bodies and 'total discs' on the sectioned stained and mounted specimens, (Tables 3 and 4). Contraction artefact was expressed as a percentage of the original measurement. Contraction after fixation and dehydration was measured (though not recorded) on repeat x-rays but this was slight, most of the contraction occurring during embedding in low viscosity nitrocellulose, sectioning, staining, and mounting. Contraction artefact was estimated only for decalcified, L.V.N. embedded material. A few measurements on wax embedded discs (compared with L.V.N. embedded discs from the same individual) suggested that contraction artefact was greater in wax embedded than in L.V.N. embedded material.

Contraction artefact was much greater as measured in specimens which were split sagittally after fixation but before embedding (Nos. 40, 52 and 59) than in specimens where the discs were embedded whole, (Tables 3 and 4). Specimens Nos. 40, 52, 59 and 60 were the only ones split in this way before embedding. (Specimen 60 was not measured fresh and the degree of contraction could not be estimated).

ESTIMATION OF VERTICAL CONTRACTION ARTEFACT

Vertical Dimensions Measured -

(a) Height of 'Total Block' of tissue: 'TOTAL'

(b) Sum of heights of 'Bony Vertebral Bodies': 'V.B.s'

(c) Sum of heights of 'Total Discs': 'DISCS'

In column 3 the figures in brackets represent the number of disc measured in each block. (a.n. = antenatal).

TABLE 3(a)

Blocks of Tissue Embedded Whole in L.V.N.

Case No.	Age	Dimensions of Fresh Specimens in mm.			Dimensions of Mounted Specimens in mm.			% Contraction		
		'TOTAL'	V.B.s	'DISCS'	'TOTAL'	V.B.s	'DISCS'	'TOTAL'	V.B.s	'DISCS'
19L	36w (a.n.)	47.0	25.1	(5)21.90	45.0	24.1	21.00	4.3	4.0	4.1
33L	40w (a.n.)	51.8	36.3	(4)15.50	48.7	34.3	14.35	6.0	5.5	7.4
34L	40w (a.n.)	-	-	(1) 3.65	-	-	3.45	-	-	5.5
44L	6m.	63.5	47.7	(4)15.70	59.3	44.3	14.90	6.6	7.1	5.1
45L	10m.	-	-	(1) 4.60	-	-	4.45	-	-	3.3
57T	4yr. 9m.	29.8	25.4	(1) 4.40	27.9	23.7	4.10	6.4	6.7	6.8
57L	4yr. 9m.	-	-	(2)16.70	-	-	15.30	-	-	8.4
					Average % contraction -			5.8	5.8	5.5

Observations - (i) If cases 34L, 45L and 57T were excluded, on the grounds that the dimensions of the discs measured were small, and the error in % contraction may have been correspondingly great, then the average % contraction was 6.2%. (ii) The most reliable measurements were likely to be those on the 'TOTAL' specimens since only one measurement of a relatively large dimension was made in each case. Here the average contraction was 5.8%.

On this basis the correction made in measurements on sections, for comparison with measurements on radiographs was one of 6%. The section measurement was multiplied by a factor of 1.06.

TABLE 3(b)

Vertical Contraction Measured in Median Sagittal Sections of Blocks Sagitally Split after Fixation and before Embedding in L.V.N.

Case No.	Age	Dimensions of Fresh Specimens in mm.			Dimensions of Mounted Specimens in mm.			% Contraction		
		'TOTAL'	V.B.s	'DISCS'	'TOTAL'	V.B.s	'DISCS'	'TOTAL'	V.B.s	'DISCS'
40T	3½ m.	27.2	21.4	(2)5.90	23.9	19.0	4.80	12.1	11.2	18.6
40L	3½ m.	12.5	8.9	(1)3.70	10.8	7.8	2.90	13.6	12.4	21.6
52T	2yr. 8m.	25.7	22.3	(1)3.40	23.0	20.1	3.00	10.5	9.9	11.8
52L	2yr. 8m.	19.0	13.6	(1)5.90	16.8	12.1	4.90	11.6	11.0	16.9
59T	7½ yrs.	47.8	39.4	(2)8.45	43.7	36.4	7.30	8.6	7.4	13.6
59L	7½ yrs.	24.3	16.2	(1)8.20	21.6	15.0	6.50	11.1	7.4	20.7
					Average % contraction -			11.2	9.9	17.2

A much greater degree of contraction artefact has taken place in sections near the 'midline surface' of the block of tissue, particularly in the discs, during decalcification, dehydration and embedding in L.V.N.

ESTIMATION OF HORIZONTAL CONTRACTION ARTEFACT

TABLE 4(a)

Blocks Embedded Whole

No.	Maturity	Dimensions of Fresh Specimens in mm.		Dimensions of Mounted Specimens in mm.		% Contraction	
		A.P.D.	L.D.	A.P.D.	L.D.	A.P.D.	L.D.
19L	36wks. a.n.	10.84(m.)	-	10.38(m.)	-	4.2%	-
33L	40wks. a.n.	13.15(m.)	-	12.33(m.)	-	6.2%	-
34L	40wks. a.n.	11.00	-	10.35	-	5.9%	-
44L	6 months	14.50(m.)	26.00	14.00(m.)	24.40	3.4%	6.2%
45L	10 months	16.30	-	14.90	-	8.6%	-
50L	2 years	-	29.00	-	27.00	-	6.9%
57T	4 yrs. 9 m.	22.50	-	21.70	-	3.6%	-
57L	4 yrs. 9 m.	29.00	38.50	26.70	36.50	7.9%	5.2%
			Average % contraction for all ages -			5.7%	6.1%

(Some lateral diameters are not recorded because of lack of clarity on A.P. X-ray)
(a.n. = antenatal, m. = mean)

TABLE 4(b)

Blocks Sagittally Split near the Midline after Fixation but before Embedding in L.V.N.

No.	Maturity	Dimensions of Fresh Specimens in mm.		Dimensions of Mounted Specimens in mm.		% Contraction	
		A.P.D.	L.D.	A.P.D.	L.D.	A.P.D.	L.D.
40T	$3\frac{1}{2}$ months	12.45	-	11.50	-	7.6%	-
40L	$3\frac{1}{2}$ months	14.00	24.40	12.50	22.50	10.7%	7.8%
52T	2 yrs. 8 m.	17.85	24.00	17.00	22.00	4.8%	8.3%
52L	2 yrs. 8 m.	21.60	35.00	20.10	31.50	6.9%	10.0%
			Average % contraction for all ages -			7.5%	8.7%

(59 is omitted because of lack of clarity in the soft-tissue images on the X-rays)

These measurements gave an average of 6% vertical contraction during processing when all ages were used. This figure was used as a basis for corrections made on vertical measurements of 'total disc' and 'vertebral body' heights. Where these data were tabulated together with measurements made on radiographs, each measurement made on a mounted section was multiplied by a factor of 1.06.

All other measurements on sections were expressed as measured, without correction, except for measurements of the 'disc proper' and cartilage plates on specimens Nos. 40, 52, and 59, where corrections were made to bring these measurements into line with the 'average' vertical contraction of 6%.

(b) Volume Contraction in the Notochordal Nucleus Pulposus. Three consecutive lumbar discs were obtained from each of eight individuals. The volumes of the 'nuclei' of L 2-3 and L 4-5 were determined by a displacement method on the fresh specimens, and the volume of L 3-4 nucleus was estimated by planimetry on tracings of sectioned specimens.

The displacement method involved weighing a block of tissue including the total disc in air and in kerosene and reweighing the same block in air and in kerosene after splitting it and gently scooping out the viscous, semiliquid nucleus pulposus. It was found that complete removal of the nucleus without removal of part of the surrounding disc was difficult to achieve. The result appeared to vary according to the speed with which the removal of the 'nucleus' and the weighing procedure were carried out, due to

ESTIMATION OF VOLUME CONTRACTION ARTEFACT

Volumes Measured -

(a) Volume of soft 'viscous fluid' centre of fresh disc (Displacement method).

(b) Volume of 'notochorial nucleus pulposus' in mounted sections (Planimetry).

TABLE 5

Case No.	Age	Disc	(a) Fresh N.P. in ml.		Disc	(b) 'Mounted' N.P.	% Contraction
			Each N.P.	Mean		in ml.	
5	30 w. (a.n.)	L 2-3 L 4-5	- -	0.029	L 3-4	0.026	10.3
10	32 w. (a.n.)	L 2-3 L 4-5	0.049 0.061	0.055	L 3-4	0.040	27.3
13	34 w. (a.n.)	L 2-3 L 4-5	- -	0.038	L 3-4	0.028	26.3
15	34 w. (a.n.)	L 2-3 L 4-5	-	0.042	L 3-4	0.040	4.8
35	40 w. (a.n.)	L 2-3 L 4-5	0.065 0.062	0.0635	L 3-4	0.060	5.5
38	2 months	L 2-3 L 4-5	0.075 0.108	0.0915	L 3-4	0.083	9.3
45	10 months	L 2-3 L 4-5	0.420 0.330	0.375	L 3-4	0.290	22.7
56	4 years	L 2-3 L 4-5	0.550 0.630	0.590	L 3-4	0.444	24.7
				Average % contraction for all ages - 16.4			

In specimens 5, 13 and 15 the two discs were weighed together.

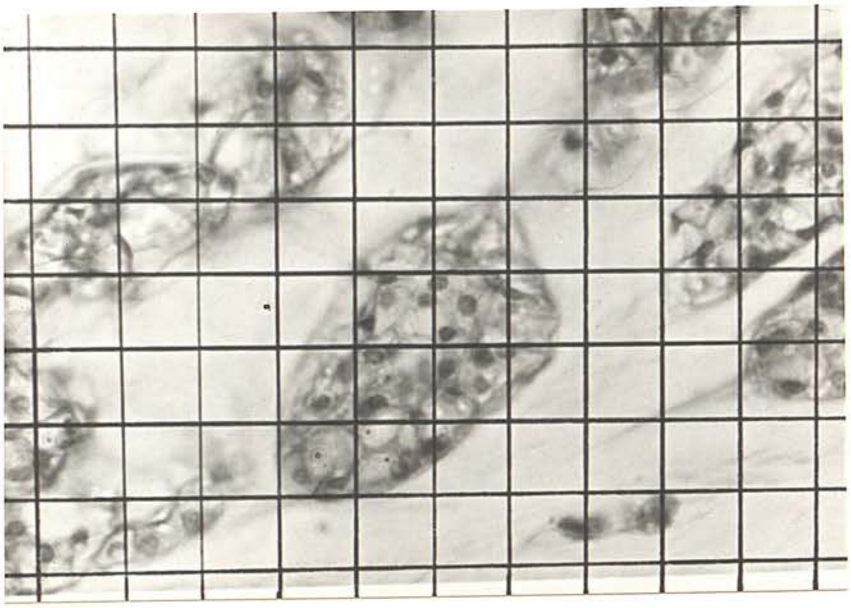
loss of weight of the specimen by evaporation of water. This loss could be seen on the balance, when weighingin air. This method of volume estimation was considered to be much less accurate than estimation of volume by planimetry on tracings of projected sections. The estimated volumes were recorded in Table 5. Since the volume of L 3-4 appeared approximately equal to the mean volume of L 2-3 and L 4-5 from the same individual at the same age, it was possible to make a rough estimate of the loss due to processing. The estimated loss also shows wide variation.

7. Notochordal Cell Counts

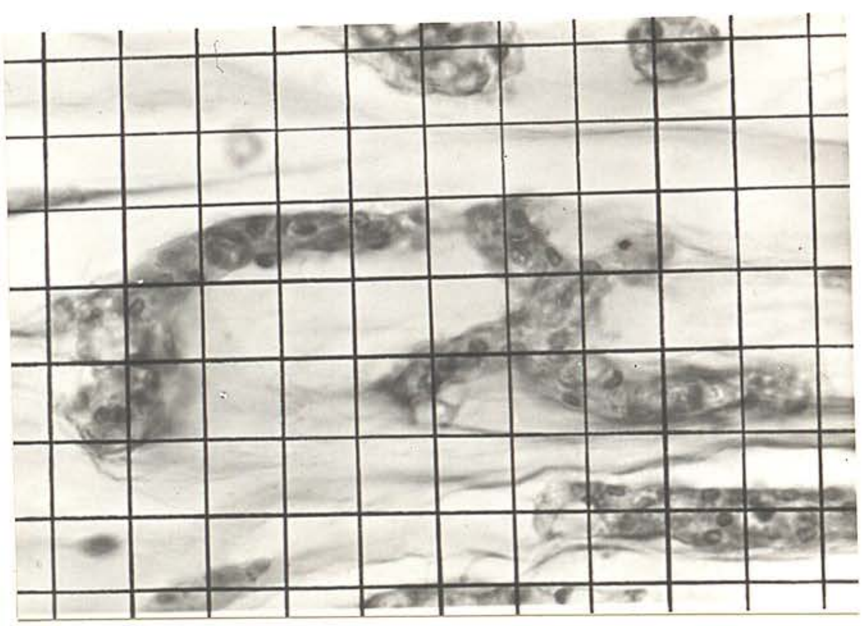
Since published opinions vary widely on the question of continued multiplication and activity of notochordal cells, an attemptwas made to estimate the relative (not the absolute) number of notochordal cells in the lumbar disc at different stages of development. In twenty specimens of lumbar discs from foetuses infants and children, an index of the total number of notochordal cells in each nucleus pulposus was obtained using a calibrated grid eye-piece graticule.

(a) Nuclear Counts. At times 480 magnification the number of notochordal cell nuclei per 100 grid squares was counted on a number of cell clumps and strands (Text fig. 12b) in different parts of the notochordal nucleus pulposus. Most counts were done on thick (150 micron) sections counting the nuclei visible in one focal plane. (The focal plane is less than the thickness of the 10 micron sections used for specimens Nos. 1 and 2). It was recognised that the counts could only be approximate in the thick sections where the nuclei

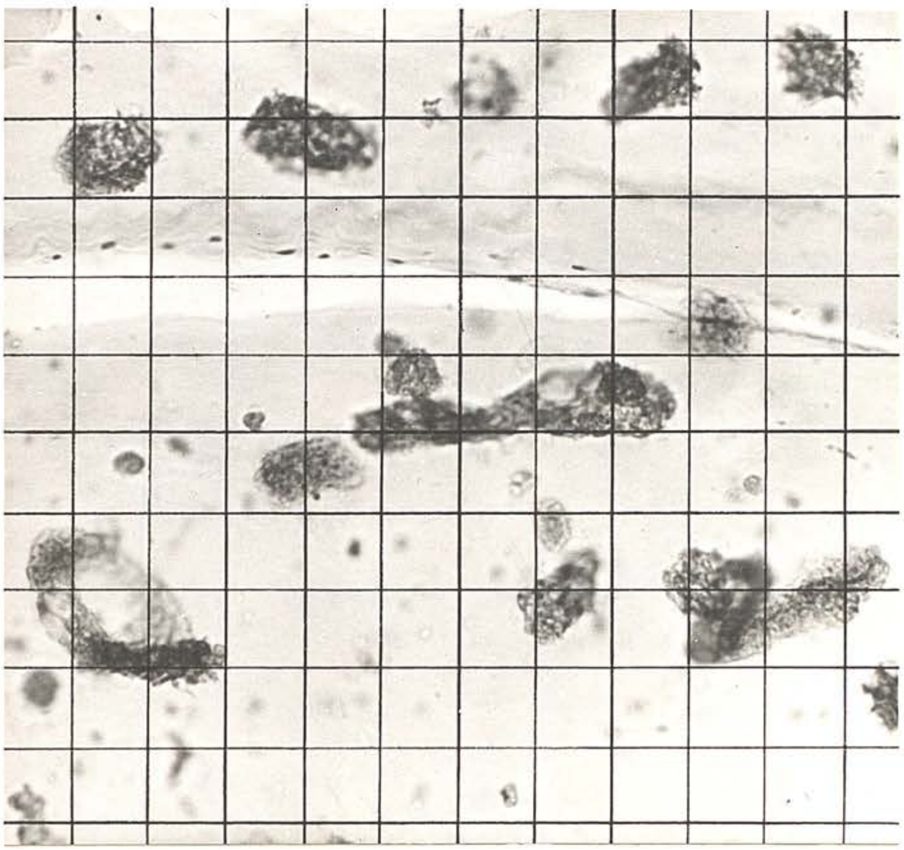
Text-fig. 12 b



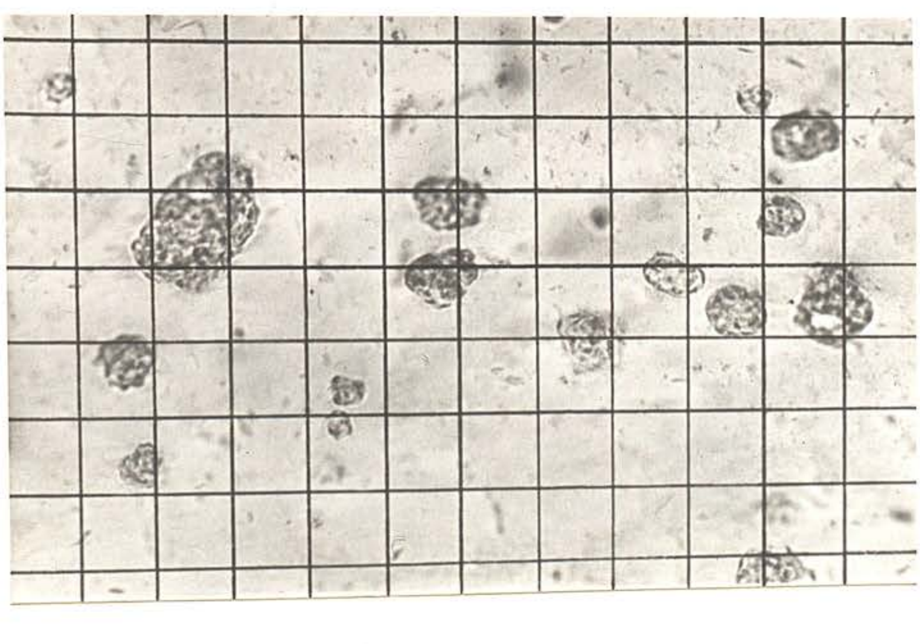
Notochordal cell clumps, x 480



Text-fig. 12 a



Notochordal cell clumps, x 120



counted were not necessarily all in sharp focus, but repeat counts gave fairly consistent results ($\pm$ 5%).

(b) Percentage of the Notochordal Nucleus occupied by Notochordal cells. Post-natal increase in the volume of the notochordal nucleus appears to be largely due to an increase in clear mucoid matrix, with dispersal of notochordal cell clumps. In lumbar discs distribution of cell clumps throughout the nucleus appears fairly uniform. The percentage area of the nucleus occupied by cell clumps (as opposed to matrix) was estimated at times 120 magnification, counting the number of grid squares and parts of grid squares occupied by these cell clumps throughout the median sagittal section (Text fig. 12a).

(c) Index of Notochordal Cell Number per Disc. The Nuclear count done on a sample of cell clumps, multiplied by the percentage of the nucleus occupied by such clumps gave an index of notochordal cell density for that nucleus. The notochordal cell density multiplied by the volume of the nucleus (determined by planimetry) gave an index of the notochordal cell number in the disc. Results were listed in Table 13.

8. Study of the Blood Supply of the Disc.

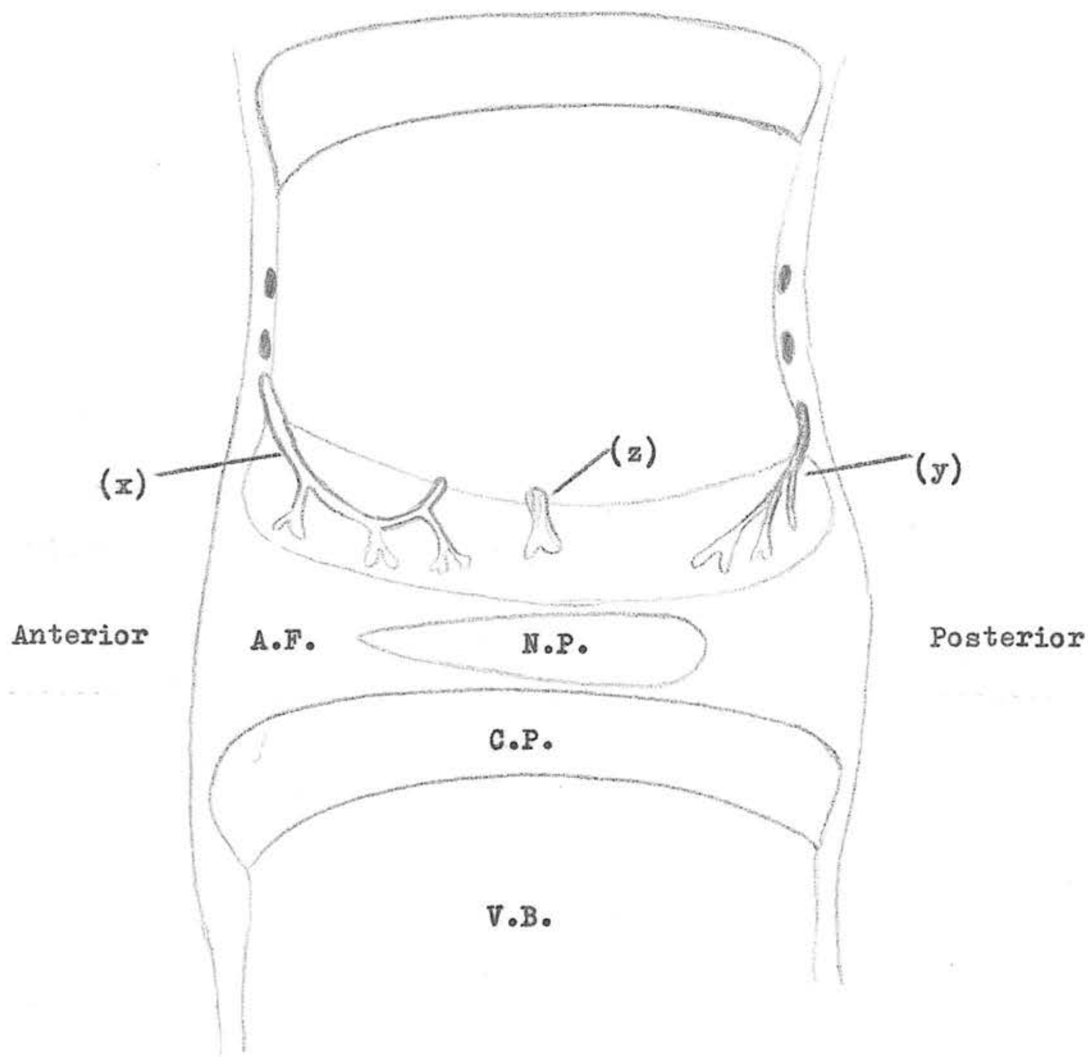
(a) Study of the vasculature of discs in foetuses and newborn infants

i Microscopy and description of blood vessels seen in sections.

ii Tracing of projections of canals containing blood vessels in the cartilage plates of serial sections from cases Nos. 10, 18 and 38. Similar projection and tracing of vascular canals in 'consecutive' sections from cases Nos. 6 and 23. Blood vessels were numbered and

Text Figure 13

Diagram of Sagittal Section of Newborn Lumbar Disc
Showing Typical Blood vessel Patterns in Cartilage Plate



(x) - loop from periosteum to marrow
(y) - blind ending canal from periosteum
(z) - blind ending canal from marrow.

(A.F. - anulus fibrosus, N.P. - nucleus pulposus, C.P. - cartilage plate, V.B. - 'bony vertebral body'.)

tracings were superimposed to check the identity in successive sections of a 'blood vessel system'. This was possible with a fair degree of accuracy in serial sections, but more difficult in 'consecutive sections' where a greater degree of error in identification of 'blood vessel systems' is likely. (One blood vessel system often extended through several 150 micron sections).

iii Classification and counting of the vascular canals: After examination of a series of discs, vascular canals were classified into three categories (see Text fig. 13) x.- loops from the vertebral periosteum, to the vertebral marrow space, y.- blind ending canals from the vertebral periosteum, and z.- blind ending canals from the bony vertebral body. The number of each of these three types found in tracings of the cartilage plates of Nos. 6, 18 and 38 was counted and expressed as a percentage. (Table 22, p. 168).

(b) Correlation of Vascularity with Disc Volume and Age. The numbers of vascular canals in the cartilage plates were counted in sections of nine lumbar discs (Nos. 4, 6, 22, 23, 42, 43, 46, 55 and 59). From the volume of each 'disc proper' estimated by planimetry, an index of vascularity per unit volume could be calculated for each disc. Changes in the size and character of vascular canals with age were noted.

6. Horizontal Measurements from Schmorl's nodes in Adults.

Fifteen vertebral columns from adult dissecting room cadavers were sagitally sectioned in the median plane using a band saw, and a search was made for Schmorl's nodes.

Horizontal measurements from the centre of Schmorl's nodes to the anterior and posterior surfaces of vertebral bodies were recorded in six adults. (Table 11 c).

X-RAY MATERIAL

A. SOURCES

Radiographs of normal vertebral columns were extracted (1) from the files 1965 to 1971 at the Royal Hospital for Sick Children, Edinburgh. (2) from the collection of the scoliosis clinic at the Princess Margaret Rose Hospital, Edinburgh. Radiographs had been taken at a tube-film distance of 36" and with the subject in the supine position (otherwise the film was clearly marked "erect").

B. SELECTION OF SUITABLE RADIOGRAPHS

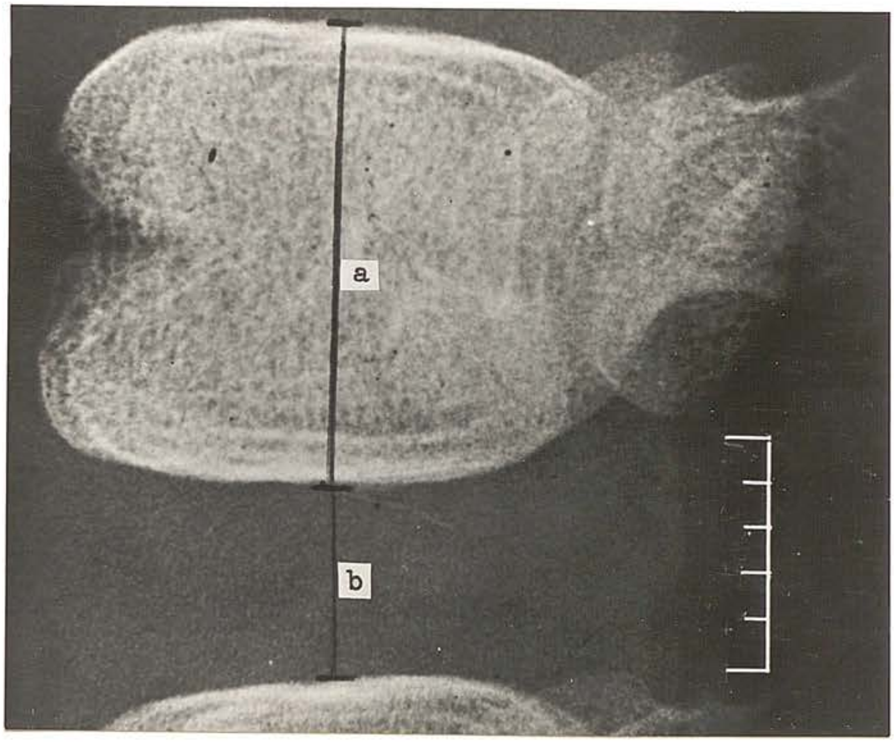
Measurements were only made on vertebrae and discs of normal appearance in regions of the vertebral column of normal appearance. This involved a high rate of rejection of radiographs examined, particularly with these at the scoliosis clinic. Though in many cases both the A.P. and lateral radiographs were available, the measurement recorded was usually made on a lateral radiograph (72% of all recorded measurements) though each measurement was checked where possible by a measurement made on another film taken at the same time.

Only true lateral or A.P. radiographs of the disc under investigation were measured. In the case of A.P. radiographs it was also necessary that spinal curvature should be minimal or absent. The spinal curvature is reduced in the supine position.

C. MEASUREMENTS

1. Vertical Measurements. Measurements of the vertical radiolucent space corresponding to the 'total disc' height, and of the height of the bony vertebral body rostral to each disc, were made

Text-fig. 14



a = 'vertebral body'

b = 'total disc'

(a 5 mm. grid is shown)

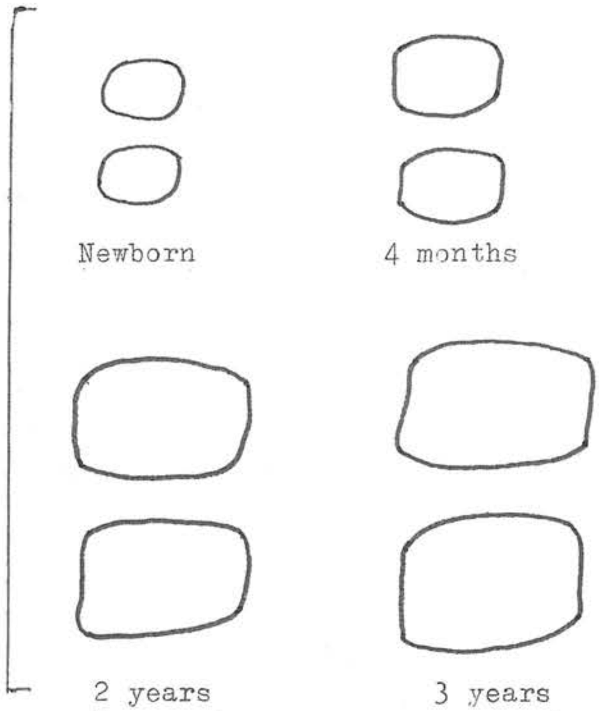
VERTICAL MEASUREMENTS ON RADIOGRAPHS

TABLE 6

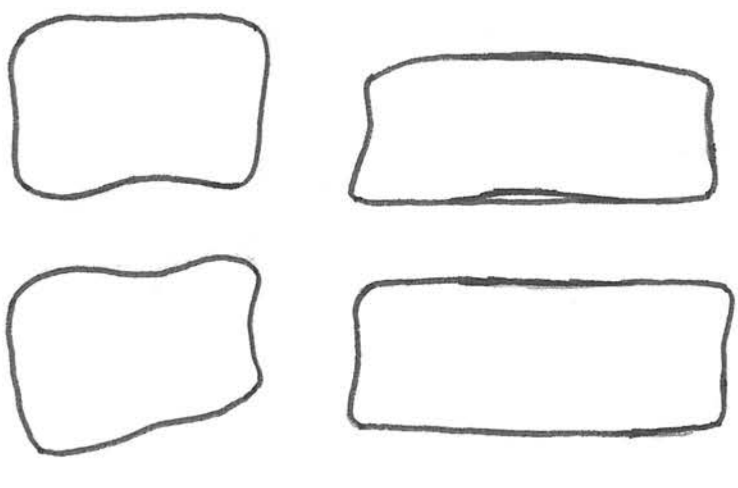
Age	Number of Radiographs Measured		
	C 5 and C 5-6	T 8 and T 8-9	L 4 and L 4-5
Newborn	-	6	8
1 to 6m.	2	19	22
$6\frac{1}{2}$ to 12m.	5	13	19
1yr. to 1yr.6m.	3	15	18
1yr.7m. to 2yr.6m.	-	24	29
2yr.7m. to 3yr.6m.	-	13	23
3yr.7m. to 4yr.6m.	4	15	25
4yr.7m. to 5yr.6m.	-	15	23
5yr.7m. to 6yr.6m.	-	14	26
6yr.7m. to 7yr.6m.	3	10	23
7yr.7m. to 8yr.6m.	5	9	25
8yr.7m. to 9yr.6m.	-	7	18
9yr.7m. to 10yr.6m.	1	12	18
10yr.7m. to 12yr.6m.	3	12	26
12yr.7m. to 14yr.6m.	-	6	7
Adults	3	-	11
TOTALS	29	190	321

Text-fig. 15

Tracings of Bony Outlines from Radiographs to show Correspondence of 'Total Disc' Height as measured in Lateral and A.P. Radiographs.



'Total Disc' height, measured midway between A and P borders, corresponds to the narrowest part of the 'Disc Space' - which is the 'Space' measured in an A.P. radiograph.



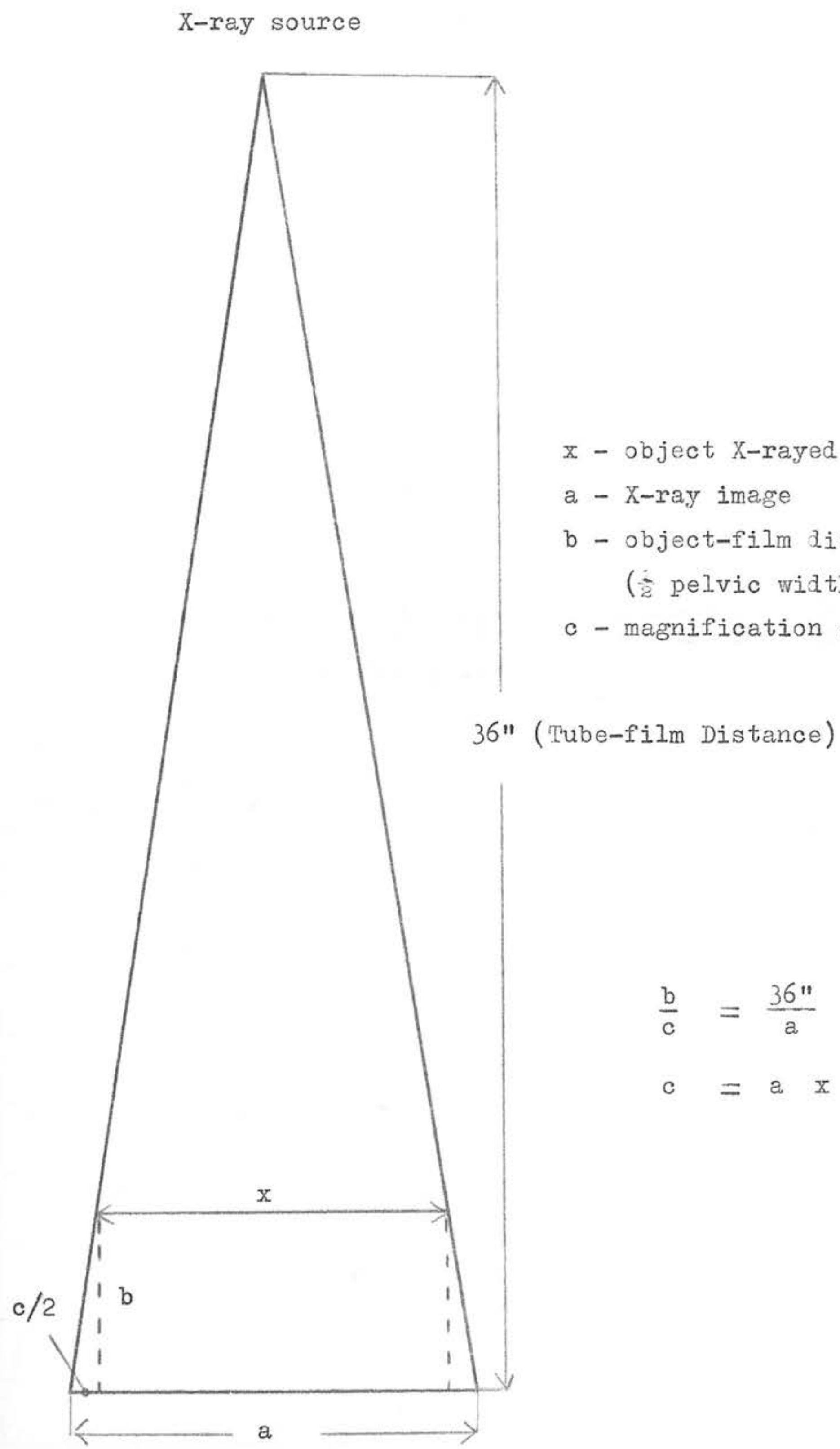
midway between the anterior and posterior surfaces, on a viewing box using a scale calibrated to the nearest 0.1mm. (Text fig. 14) with the aid of a hand lens for all except the largest cases. Measurements made on suitable A.P. radiographs were comparable (Text fig. 15) in younger subjects, because of the minimal vertebral column curvature and the convexity of the bony vertebral **body** end-surfaces, and in older subjects, where the central part of the bony vertebral body end-surface was concave, (due to nucleus pulposus growth) it was seen as a separate image on the radiograph (Text fig. 15).

(a) Preliminary study. In order to ascertain the relative dimensions of neighbouring discs in the lumbar, thoracic and cervical regions, (i) the approximate heights of all lumbar vertebrae and discs (to the nearest 0.1mm. in most smaller cases and to the nearest 0.5mm. in most larger cases) were measured in 40 lumbar vertebral columns. These were listed in order of maturity, and arbitrarily divided into four groups (under 1 year, 1-4 years, 5-7 years, and 9-13 years). For these groups, the mean height of each lumbar vertebra and disc was calculated. (ii) Comparisons of different lower cervical and mid-thoracic discs were also made on a small number of cases in each region.

(b) Definitive Study. The discs L 4-5, T 8-9 and C 5-6 and the vertebrae rostral to them were measured. Table 6 lists the number of measurements made in each region according to age. Total disc heights were measured to the nearest 0.05mm. and bony vertebral body heights to the nearest 0.1mm. The data were grouped and tabulated according to age, together with post-mortem data, and corrected for magnification error. (Table 8).

Text Figure 16

Calculation of Magnification Error



x - object X-rayed

a - X-ray image

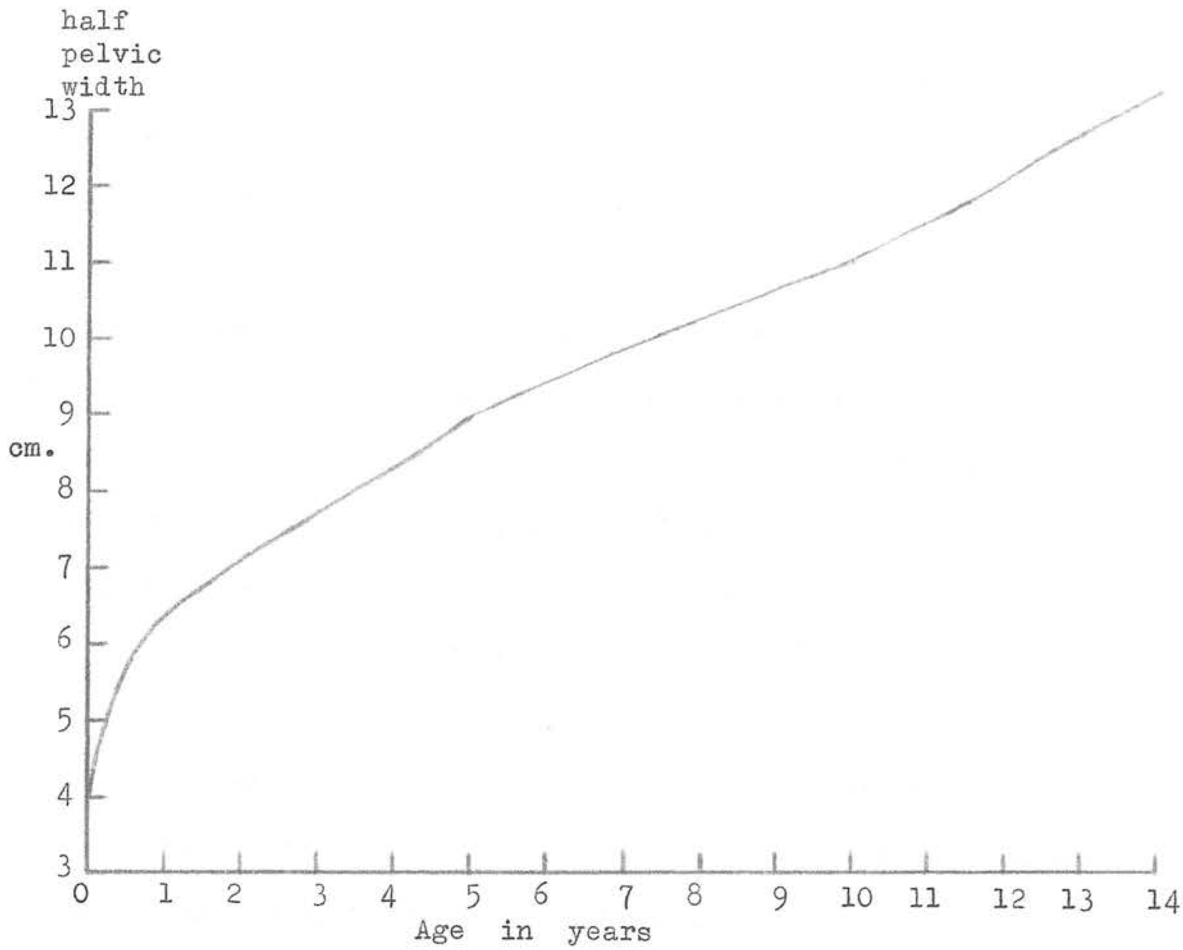
b - object-film distance ($\frac{1}{2}$ pelvic width)

c - magnification error

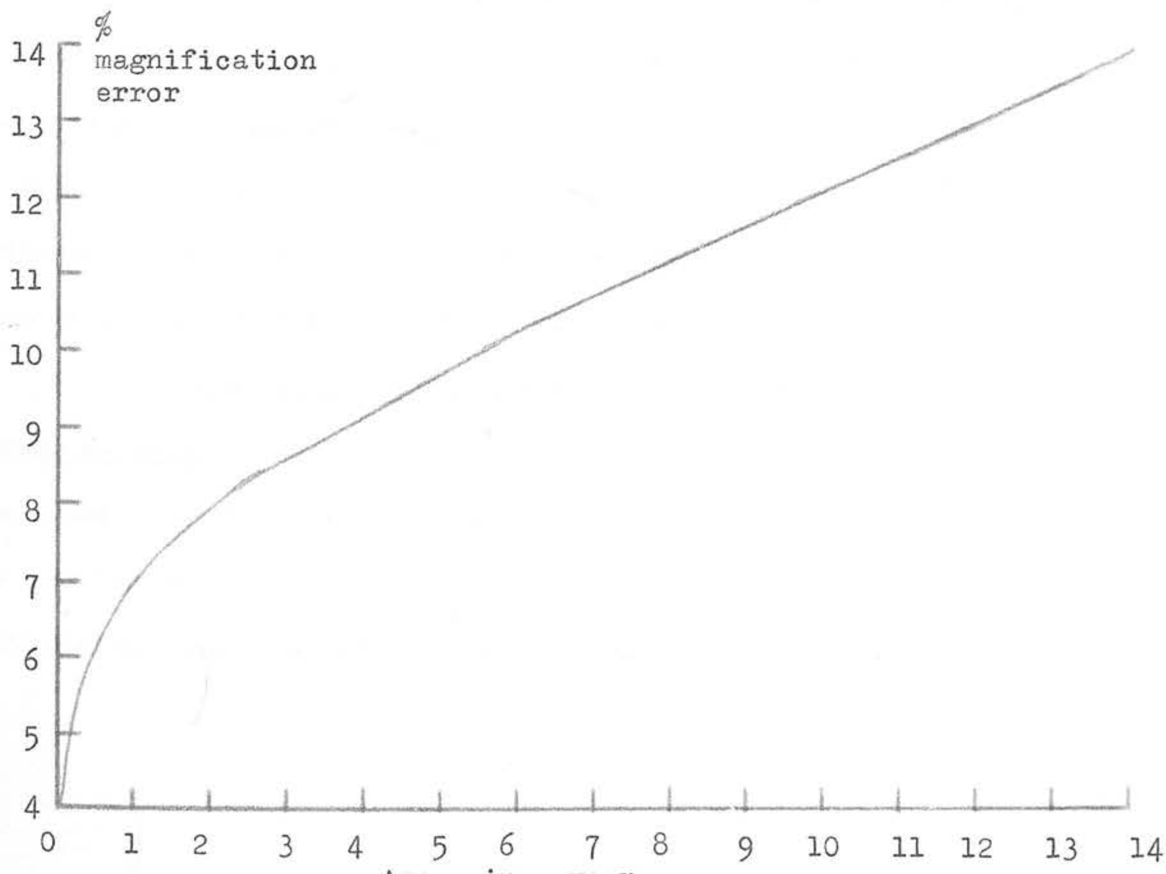
$$\frac{b}{c} = \frac{36"}{a}$$

$$c = a \times \frac{b}{36}$$

Text-fig. 17



half pelvic width
cm.
13
12
11
10
9
8
7
6
5
4
3
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Age in years



% magnification error
14
13
12
11
10
9
8
7
6
5
4
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Age in years

2. Corrections for Magnification Error. Magnification error was dependent on the width of the pelvis, thorax, or shoulders in the lateral radiographs of the lumbar thoracic and cervical regions respectively. This information was not available for each individual, but data on the average pelvic width at all ages, (Stuart & Stevenson, 1959) was used to construct a graph of half pelvic width increase with age. (Where there were sex differences the mean was used). Since a uniform tube-film distance of 36" was used for all radiographs, the magnification error could be calculated on the basis of:-

$$\text{magnification error} = \frac{\text{measurement of image}}{\text{on radiograph}} \times \frac{\frac{1}{2}\text{ pelvic width}}{36''}$$

e.g. at ten years = 4.35/36 = 0.12 or 12%. (Text fig. 16). Since the pelvic width is approximately equal to the lateral thoracic and biacromial diameters, the same correction factors were used for all three regions. In practice, by comparison of measurements made of the same structure on both A.P. and lateral radiographs, magnification error on A.P. radiographs was found to be approximately half of that in lateral radiographs. Corrections for error in A.P. radiographs were therefore arbitrarily fixed at half of the corresponding correction for the lateral radiograph at the same age.

3. Correlation of Vertical Measurements on X-rays and Post-mortem Material. Measurements made on radiographs were corrected as described. Linear vertical measurements on sectioned and mounted post-mortem material were corrected for contraction artefact by multiplying them by a factor of 1.06 to allow for the average of

6% contraction artefact, established as described. Total disc heights and bony vertebral body heights as determined on radiographs and on sections were grouped together for a study of vertical growth.

4. Horizontal Measurements on Radiographs. In radiographs of 49 subjects, estimates of the horizontal dimensions of L 4-5 were made by measuring the A.P. diameter at the lower surface of L 4, and taking the mean of the lateral diameters of L 4 and L 5 as measured where they bound the disc space, (see Table 17).

RESULTS

AND

DESCRIPTION

including Tables 7 - 23

and Text-figures 18 - 102

TABLE 7(a)

RADIOGRAPHIC COMPARISON OF HEIGHTS OF ALL LUMBAR VERTEBRAE AND DISCS

(40 cases)

Age	Heights in mm.								
	L1	L1-2	L2	L2-3	L3	L3-4	L4	L4-5	L5
36 weeks	5.0	3.3	4.9	3.6	4.8	4.0	4.6	4.4	4.7
40 weeks	6.8	3.3	7.5	3.5	7.8	4.0	8.0	4.3	7.3
40 weeks	6.8	3.3	7.2	3.6	7.4	3.8	7.6	4.0	7.2
40 weeks	8.2	3.0	8.3	3.2	8.3	3.5	8.0	3.6	8.0
2 months	8.5	2.8	8.8	3.0	9.0	3.3	9.0	3.8	8.7
3 months	9.5	4.4	9.5	4.5	9.7	4.3	10.0	5.0	8.6
6 months	9.5	3.5	9.8	3.9	10.2	4.2	9.6	4.1	8.8
7 months	11.3	4.5	11.5	4.8	11.5	5.0	11.0	4.7	10.3
$7\frac{1}{2}$ months	10.5	3.5	11.0	3.5	11.5	4.0	11.5	3.9	11.0
means (mean age = 3m)	8.46	3.51	8.72	3.73	9.00	4.01	8.81	4.20	8.29
1 year	11.5	4.5	12.0	4.5	12.5	4.8	12.3	5.2	11.5
1 yr. 10m.	14.0	4.0	14.0	4.0	13.5	4.5	13.5	4.5	13.0
2 years	16.0	5.0	16.0	5.5	15.2	6.0	14.2	5.8	13.5
2 yrs. 4 m.	15.0	5.2	15.0	5.5	15.5	5.6	15.8	5.5	15.5
2 yrs. 10 m.	15.0	5.7	16.0	5.7	17.0	6.3	17.0	6.5	16.0
4 years	17.5	7.5	18.0	8.5	17.0	9.5	17.0	9.5	16.5
4 years	16.0	6.0	17.0	6.0	17.0	6.5	17.8	7.1	16.5
4 years	17.0	6.0	18.0	7.0	18.0	7.0	18.0	7.5	16.0
4 yrs. 4 m.	17.0	6.5	17.5	7.0	17.4	8.0	16.3	7.5	16.0
4 yrs. 4 m.	15.5	7.0	16.0	8.0	15.5	8.6	15.5	8.5	15.0
means (mean age=3yrs)	15.45	5.74	15.95	6.17	15.86	6.68	15.74	6.76	14.95

TABLE 7(a) (contd)

Age	Heights in mm.								
	L1	L1-2	L2	L2-3	L3	L3-4	L4	L4-5	L5
5 years	19.5	6.5	19.0	8.0	18.5	8.0	17.5	8.8	17.0
5 years	18.0	5.8	18.0	6.0	18.0	6.7	18.0	7.5	18.0
5 years	17.0	6.7	18.0	7.0	17.5	8.5	17.0	8.7	16.5
6 years	16.5	9.0	17.0	10.0	16.5	10.5	16.5	10.5	16.5
6 years	22.5	8.0	22.0	8.0	23.0	9.0	21.0	10.0	18.0
6 years	20.0	8.6	20.5	8.7	19.5	9.3	20.0	9.5	18.5
6 years	19.0	6.0	19.0	6.3	18.5	7.7	16.0	8.5	15.0
6 years	17.5	9.2	17.5	10.0	18.0	10.2	18.0	10.5	17.2
6 years	17.8	6.7	18.0	7.0	17.5	8.5	17.0	8.7	16.5
7 years	18.5	8.0	18.8	9.0	19.0	9.2	19.0	9.7	17.5
7 years	19.5	7.0	20.5	8.0	21.0	8.5	20.0	9.0	20.0
7 years	21.0	9.0	21.0	9.5	21.0	10.5	21.0	10.5	20.0
means (mean age=6yrs)	18.90	7.54	19.11	8.13	19.00	8.88	18.42	9.33	17.56
9 years	21.5	8.6	21.5	8.5	21.5	8.5	22.0	8.7	22.0
9 years	21.0	8.0	21.0	8.3	21.0	8.7	21.0	8.5	21.0
9 years	21.0	7.0	21.0	9.0	21.5	9.0	22.0	10.0	20.0
9 years	23.0	10.0	23.0	10.0	22.5	11.0	24.0	10.0	24.0
10 years	21.0	9.5	21.0	10.5	21.0	11.0	21.5	11.5	21.5
10 years	23.0	8.5	23.0	10.5	23.0	11.0	22.5	12.0	20.0
11 years	21.0	7.0	21.5	8.5	21.5	8.5	21.5	9.5	20.0
13 years	25.0	10.0	25.0	11.0	25.0	11.0	25.0	11.0	25.0
$13\frac{1}{2}$ years	27.2	10.0	27.0	11.0	26.0	12.0	27.0	12.0	26.0
means (av. $10\frac{1}{2}$ yrs)	22.63	8.73	22.67	9.70	22.56	10.08	22.94	10.36	22.17

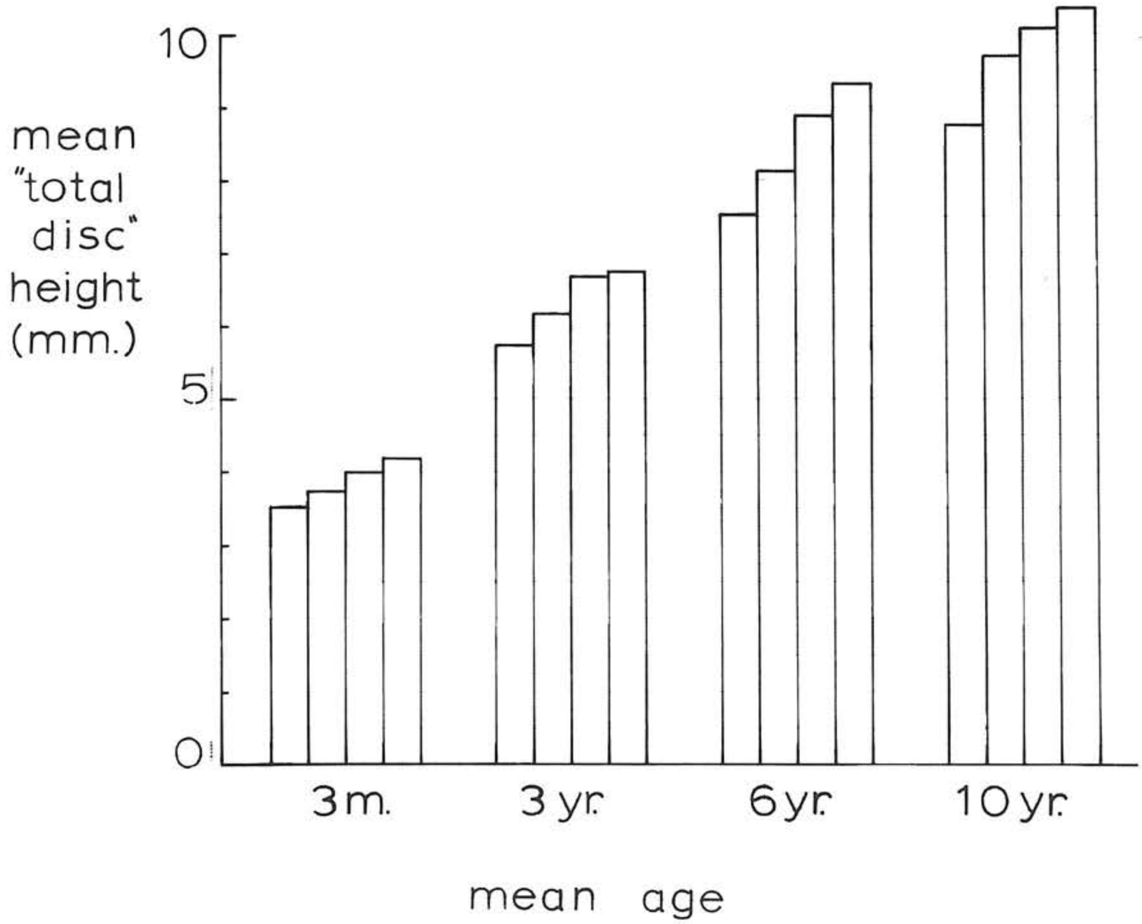
MEANS OF FOUR GROUPS

		L1	L1-2	L2	L2-3	L3	L3-4	L4	L4-5	L5
Group 1 under 1 year	9 cases average 3m.	8.46	3.51	8.72	3.73	9.00	4.01	8.81	4.20	8.29
Group 2 1 - 4½ years	10 cases average 3 yrs.	15.45	5.74	15.95	6.17	15.86	6.68	15.74	6.76	14.95
Group 3 5 - 7 years	12 cases average 6 yrs.	18.90	7.54	19.11	8.13	19.00	8.88	18.42	9.33	17.56
Group 4 9 - 14 years	9 cases average 10½ yrs	22.63	8.73	22.67	9.70	22.56	10.08	22.94	10.36	22.17
Overall aver-ages	40 cases average 5 yrs.	16.36	6.38	16.61	6.93	16.61	7.41	16.48	7.66	15.74
Rounded to nearest 0.1 mean		16.4	6.4	16.6	6.9	16.6	7.4	16.5	7.7	15.7

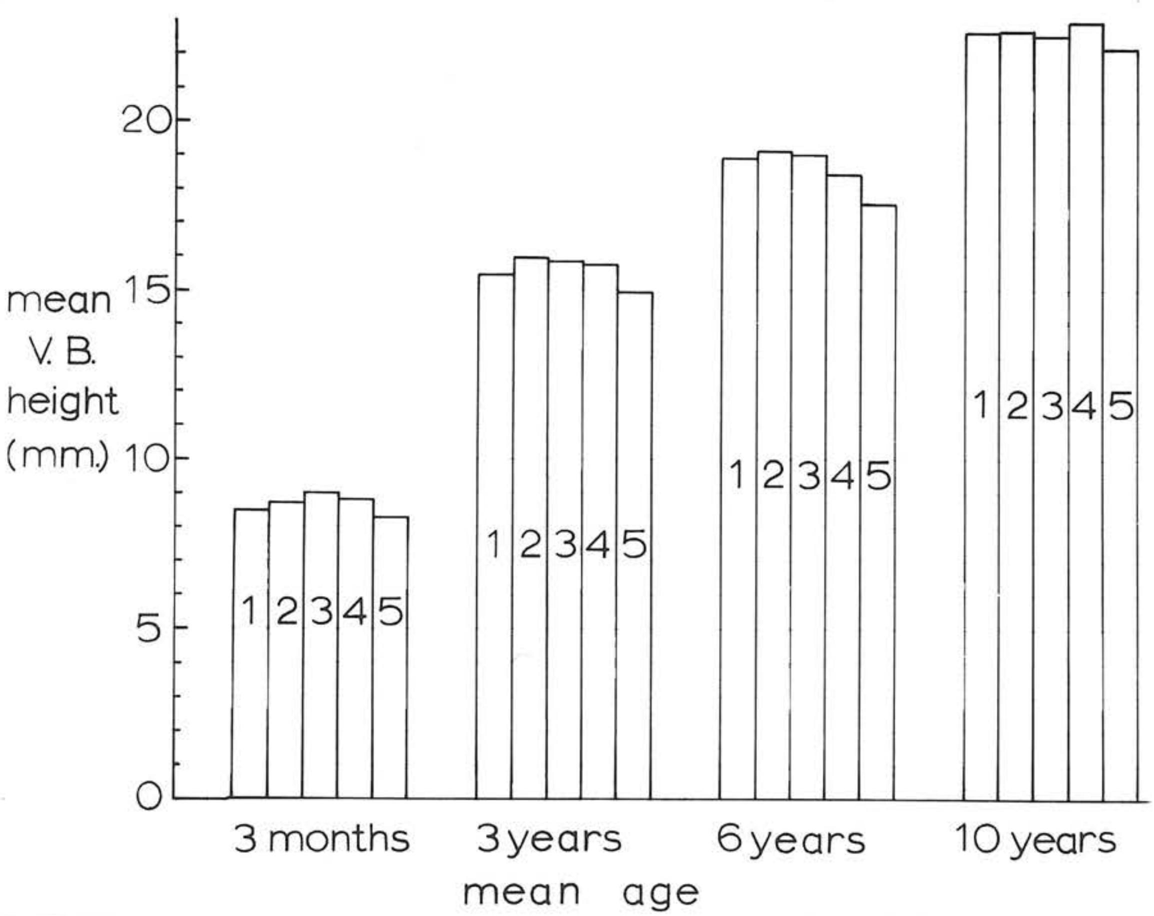
Text-fig. 18

(a) Mean heights of lumbar vertebral bodies for four age groups. (Table 7 a).

(b) Mean heights of lumbar 'total discs' for four age groups. (Table 7 a).



10
mean
"total
disc"
height
(mm.)
5
0
3 m.
3 yr.
6 yr.
10 yr.
mean age



20
mean
V. B.
height
(mm.)
15
10
5
0
1 2 3 4 5
1 2 3 4 5
1 2 3 4 5
1 2 3 4 5
3 months
3 years
6 years
10 years
mean age

TABLE 7(b)

COMPARISON OF THE HEIGHTS OF L3-4 and L4-5 IN SECTIONED AUTOPSY MATERIAL

No.	Age	L3-4	L4-5
19	36w.	3.40	3.50
33	40w.	4.00	4.20
34	40w.	3.70	4.00
40	3m.	3.70	4.10
44	6m.	4.30	4.20
52	2yr.8m.	6.00	5.90
57	4yr.9m.	8.60	8.50
59	7.1/2yr.	8.70	8.20
	Means	5.30	5.3

COMPARISON OF HEIGHTS OF THORACIC VERTEBRAE AND DISCS

Though many mid and lower thoracic discs and vertebrae were measured on radiograms, only the heights of T8 and T8-9 are recorded. A slight increase in the height of each successive disc and vertebra from T6-7 down to T11-12, was noted, but the difference between neighbouring discs was small and of the order of 5% or less, except for the lower two discs (T10-11 and T11-12) which were more noticeably thicker than the discs above them.

CERVICAL DISCS

Relatively few cervical discs were measured, the height of C5-6 was either slightly greater than or equal to the height of each disc rostral or caudal to it.

TABLE 8a

HEIGHTS OF VERTEBRAL BODY - L4 and of 'TOTAL DISC' - L4-5

GROUP 1. n = 10

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
3	F	25w.	3.3	3.5	2.60	2.75	0.78
4	F	29w.	4.3	4.6	3.00	3.20	0.70
6	M	30w.	4.0	4.2	3.10	3.40	0.80
7	M	30w.	5.0	5.3	2.65	2.80	0.53
8	M	31w.	4.7	5.0	2.90	3.05	0.62
11	F	32w.	5.2	5.5	3.10	3.30	0.60
14	M	34w.	5.3	5.6	3.00	3.20	0.57
16	F	35w.	5.4	5.7	3.60	3.80	0.67
17	M	35w.	5.0	5.3	3.60	3.80	0.72
19	M	36w.	4.7	5.0	3.50	3.70	0.70

GROUP 2. n = 17

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
20	F	40w.	6.3	6.7	3.20	3.40	0.51
21	M	40w.	7.4	7.8	3.50	3.70	0.47
22	F	40w.	6.6	7.0	3.50	3.70	0.53
25	F	40w.	6.6	7.0	3.60	3.80	0.55
26	F	40w.	6.0	6.4	4.30	4.55	0.72
27	M	40w.	6.0	6.4	3.40	3.60	0.57
29	M	40w.	7.1	7.5	5.00	5.30	0.70
30	M	40w.	6.3	6.7	4.20	4.45	0.67
33	F	40w.	7.8	8.2	4.20	4.45	0.54
34	M	40w.	(x-ray)	7.5	4.00	4.00	0.53
Walsh	-	40w.	7.0	6.7	3.75	3.60	0.54
McKenzie	-	40w.	AP: 7.5	7.3	3.60	3.50	0.48
McAdam	M	40w.	AP: 8.0	7.8	3.80	3.70	0.48
X-ray I	-	40w.		7.1	4.00	4.00	0.56
McFadden	M	40w.	AP: 9.7	9.5	4.40	4.30	0.45
Millar	M	40w.	L: 8.0	7.7	3.75	3.60	0.48
Tait	M	40w.	L. 8.0	7.7	3.50	3.35	0.44

GROUP 3. n = 27

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
37	M	1m.	7.5	7.9	3.40	3.60	0.45
Manson	-	1m.	AP:12.0	11.6	5.10	4.95	0.43
McFarlane	F	2m.	L: 9.0	8.6	3.75	3.60	0.42
Rae	F	2m.	AP: 8.5	8.3	3.60	3.50	0.42
Mackie	M	2m.	AP: 8.8	8.6	3.70	3.60	0.42
Ferris	M	$2\frac{1}{2}$m.	AP: 8.8	8.6	4.10	4.00	0.47
McFadden	M	3m.	AP:11.5	11.3	4.50	4.40	0.39
39	M	3m.	9.2	9.6	3.75	4.00	0.41
Sneddon	F	3m.	L: 9.4	8.9	4.35	4.15	0.46
Boyle	F	3m.	L:10.5	10.0	3.80	3.60	0.36
Stephen	F	3m.	L:10.0	9.5	3.70	3.50	0.37
Lyons	F	3m.	AP: 9.9	9.6	3.90	3.80	0.39
Walker	-	3m.	L:10.0	9.5	4.00	3.80	0.40
Thorne	F	3m.	L: 9.9	9.4	5.00	4.75	0.50
40	M	$3\frac{1}{2}$m.	(x-ray)	9.9		3.90	0.39
McLarty	F	4m.	AP:10.0	9.8	4.90	4.75	0.49
41	M	4m.	9.5	10.0	4.40	4.65	0.46
Blair	-	4m.	L: 9.5	9.0	4.80	4.50	0.51
Lear	F	5m.	L:11.0	10.4	4.60	4.30	0.42
Mair	M	5m.	L:11.2	10.6	4.80	4.50	0.43
Wishart	F	5m.	L:11.5	10.8	4.15	3.90	0.36
Murtagh	M	5m.	L:11.5	10.8	5.20	4.90	0.45
Brown	M	5m.	L:12.0	11.4	4.30	4.05	0.36
44	M	6m.	(x-ray)	9.6		4.20	0.44
Ross	F	5m.	L:10.6	10.0	4.35	4.10	0.41
Lorimer	M	6m.	AP:10.8	10.5	4.30	4.15	0.40
Thorpe	-	6m.	L:12.5	11.8	4.80	4.50	0.38

GROUP 4 (over 6m. under 1 year) n = 20.

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Baisden	F	6½m.	L: 11.5	10.8	5.00	4.70	0.43
McKay	M	7 m.	L: 11.0	10.4	4.75	4.45	0.43
King	-	7 m.	L: 12.3	11.5	4.20	3.95	0.34
Borthwick	F	7 m.	L: 12.8	12.0	5.00	4.85	0.39
Reid	F	7½m.	L: 11.5	10.8	4.05	3.80	0.35
Douglas	-	8 m.	L: 11.2	10.5	4.00	3.75	0.36
Findlay	-	8 m.	AP: 12.5	12.1	4.70	4.55	0.38
Reid	F	8½m.	L: 12.5	10.7	4.40	4.10	0.35
Bennett	F	9 m.	L: 13.0	12.1	4.50	4.20	0.35
Stephens	M	9 m.	L: 12.5	11.7	4.10	3.85	0.33
Redpath	M	9 m.	L: 13.3	12.4	4.40	4.10	0.33
McFadden	M	9 m.	AP: 13.0	12.6	4.50	4.35	0.35
Ross	F	9 m.	L: 12.3	11.5	4.85	4.55	0.39
McKay	M	10 m.	AP: 11.5	11.2	5.30	5.10	0.46
Parton	M	10 m.	AP: 12.8	12.3	4.70	4.55	0.37
Brown	M	10 m.	L: 13.3	12.4	5.20	4.85	0.39
Forsyth	F	10 m.	AP: 12.5	12.1	4.25	4.10	0.34
Robertson	F	10 m.	L: 11.5	10.7	4.05	3.80	0.35
45	F	10 m.	(x-ray)	10.5		4.70	0.45
McFarlane	F	11 m.	AP: 12.0	11.6	5.30	5.10	0.44

GROUP 5 (12 - 18 months) n = 19.

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Smith	F	1 yr.	L: 11.8	11.0	4.70	4.35	0.40
Gillies	M	1 yr.	L: 14.0	13.0	4.70	4.35	0.34
Jones	-	1 yr.	L: 13.5	12.6	6.50	6.05	0.48
Findlay	-	1 yr.	L: 13.5	12.6	5.20	4.85	0.39
Norman	F	1 yr.	L: 12.3	11.5	5.20	4.85	0.42
Spence	M	1 yr.	L: 14.0	13.0	5.00	4.60	0.36
46	M	14 m.	11.8	12.5	4.80	5.10	0.41
Ross	F	15 m.	L: 14.4	13.4	5.15	4.80	0.36
Brown	M	15 m.	L: 13.6	12.6	5.50	5.10	0.40
Patterson	M	15 m.	L: 14.0	13.0	4.70	4.35	0.34
Gardner	-	16 m.	L: 12.1	11.2	5.00	4.60	0.41
Wood	M	17 m.	AP: 12.5	12.0	4.80	4.60	0.38
Young	M	17 m.	AP: 14.5	13.9	5.50	5.30	0.38
Mitchell	F	17 m.	L: 13.8	12.8	5.20	4.80	0.38
Judge	F	18 m.	AP: 13.5	13.0	5.00	4.80	0.37
Reid	M	18 m.	L: 14.0	12.9	6.00	5.55	0.43
Scally	M	18 m.	L: 14.2	13.1	6.60	6.10	0.46
Cairns	F	18 m.	L: 13.0	12.1	5.50	5.10	0.42
McFarlane	M	18 m.	AP: 13.3	12.8	5.60	5.40	0.42

GROUP 6 (1 year 7 months to 2 years 6 months) n = 32.

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Brown	F	1yr. 7m.	AP: 13.0	12.5	4.50	4.30	0.35
Pattenden	M	1yr. 7m.	L: 15.7	14.5	5.50	5.10	0.35
48	F	1yr. 8m.	12.0	12.7	3.90	4.15	0.33
McFadden	M	1yr. 8m.	AP: 14.5	13.9	5.50	5.25	0.38
Cunningham	-	1yr.10m.	L: 15.5	14.3	6.30	5.80	0.41
McLennan	F	1yr.10m.	L: 13.5	12.5	4.50	4.15	0.33
Millar	F	1yr.10m.	L: 16.0	14.8	6.00	5.50	0.38
Scott	F	1yr.10m.	L: 14.0	13.0	5.10	4.70	0.36
Ross	F	1yr.11m.	L: 15.9	14.6	5.40	4.95	0.34
McDowell	M	2 yrs.	L: 15.0	13.8	6.00	5.50	0.40
Smith	M	2 yrs.	L: 15.0	13.8	6.50	6.00	0.43
Hanning	M	2 yrs.	L: 14.6	13.4	5.50	5.05	0.38
McCart	M	2 yrs.	AP: 14.7	14.1	6.25	6.00	0.43
Bullion	M	2 yrs.	L: 14.2	13.1	5.80	5.30	0.41
Simpson	F	2 yrs.	L: 15.0	13.8	5.00	4.60	0.33
Watt	F	2 yrs.	L: 14.8	13.6	5.50	5.05	0.37
Birrell	M	2 yrs.	AP: 13.5	13.0	6.00	5.75	0.44
McKendrick	F	2 yrs.	L: 15.5	14.3	6.10	5.60	0.39
Tulloch	F	2 yrs.	L: 13.5	12.4	5.50	5.05	0.41
(11) 49	M	2 yrs.	11.5	12.2	4.60	4.90	0.40
Davidson	F	2 yrs.+	AP: 14.0	13.4	6.20	5.95	0.44
Lorimer	M	2yrs.3m.	AP: 14.4	13.8	6.20	5.95	0.43
Wood	M	2yrs.3m.	AP: 13.0	12.5	5.10	4.90	0.39
51	M	2yrs.3m.	12.6	13.3	4.25	4.50	0.34
Thomas	M	2yrs.4m.	L: 15.5	14.2	5.50	5.05	0.35
Pinkerton	M	2yrs.5m.	L: 15.0	13.8	5.90	5.40	0.39
McLung	F	2yrs.6m.	AP: 13.9	13.3	6.20	5.95	0.45
Barrow	M	2yrs.6m.	L: 17.3	15.9	5.45	5.00	0.32
Thomson	-	2yrs.6m.	L: 14.6	13.4	4.80	4.40	0.33
Jones	F	2yrs.6m.	L: 17.3	15.9	7.20	6.60	0.42
Anderson	M	2yrs.6m.	L: 14.8	13.6	6.00	5.50	0.41
Ridgeway	M	2yrs.6m.	L: 16.2	14.9	6.80	6.25	0.42

GROUP 7 (3 years) (Range: 2 years 7 months to 3 years 6 months)
n = 25

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Grant	F	2yrs.7m.	L: 15.0	13.8	6.50	5.95	0.43
52	F	2yrs.8m.	(fresh)	14.0		5.90	0.42
Buggy	M	2yrs.9m.	L: 16.0	14.7	7.00	6.40	0.44
Perrie	F	2yrs.9m.	AP: 15.0	14.4	6.50	6.20	0.43
Bagwell	F	2yrs10m.	L: 16.5	15.1	6.70	6.10	0.41
Grant	F	2yrs10m.	L: 15.5	14.3	8.00	7.30	0.52
Robinson	M	3yrs.	L: 16.5	15.1	6.50	6.00	0.39
Virtue	F	3yrs.	L: 14.5	13.2	6.30	5.80	0.43
Davie	M	3yrs.	L: 14.5	13.2	5.90	5.40	0.41
Yule	M	3yrs.	L: 16.5	15.1	7.00	6.40	0.42
Short	-	3yrs.	L: 15.5	14.3	7.00	6.40	0.45
53	F	3yrs.	12.6	13.4	6.50	6.90	0.52
German	F	3yrs.	AP: 17.0	16.2	6.30	6.00	0.37
Tribeck	M	3yrs.	AP: 15.5	14.9	6.60	6.30	0.43
King	F	3yrs.	L: 16.5	15.1	7.00	6.40	0.42
Wardrop	M	3yrs.	AP: 16.0	15.3	7.70	7.30	0.48
Strang	M	3yrs.	AP: 15.6	15.0	6.90	6.60	0.44
Johnson	F	3yrs.	AP: 15.0	14.4	6.70	6.40	0.45
Ewart	M	3yrs.	L: 14.2	13.1	6.20	5.70	0.44
Stanton	M	3yrs.	AP: 15.0	14.4	6.55	6.25	0.44
Grieve	-	3yrs. +	L: 16.0	14.6	8.00	7.30	0.50
Walsh	-	3yrs.4m.	L: 18.0	16.5	7.70	7.05	0.43
McGrath	-	3yrs.5m.	L: 16.0	14.6	6.20	5.70	0.39
Kilpatrick	F	3yrs.6m.	L: 17.0	15.6	6.90	6.30	0.41
Knight	M	3yrs.6m.	AP: 16.0	15.2	8.00	7.60	0.50

GROUP 8 (4 years) (Range: $3\frac{1}{2}$ years to $4\frac{1}{2}$ years)

n = 25

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Buggy	M	3yrs.8m.	L: 17.0	15.5	8.20	7.50	0.48
Tennant	F	3yrs.9m.	AP: 15.4	14.7	7.00	6.70	0.45
Alcorn	M	3yrs10m.	AP: 15.2	14.5	7.50	7.15	0.49
Park	M	3yrs11m.	L: 16.8	15.3	6.50	6.00	0.39
Ross	F	3yrs11m.	L: 17.2	15.7	6.50	6.00	0.38
Wilson	-	3yrs11m.	AP: 16.0	15.2	8.00	7.60	0.50
McKenzie	F	4 yrs.	AP: 15.8	15.0	8.10	7.70	0.51
Hardie	F	4 yrs.	L: 16.5	15.0	8.55	7.75	0.52
McLaren	F	4 yrs.	L: 18.4	16.8	7.30	6.65	0.40
McFarlane	M	4 yrs.	L: 17.2	15.7	8.80	8.00	0.51
Thomson	M	4 yrs.	L: 18.0	16.4	7.50	6.90	0.42
Doig	F	4 yrs.	AP: 15.5	14.8	7.60	7.20	0.49
Welsh	F	4 yrs.	L: 16.8	15.1	8.00	7.30	0.48
Galloway	M	4 yrs.	L: 17.0	15.5	9.50	8.60	0.56
Brown	F	4 yrs.	L: 16.7	15.1	7.30	6.65	0.44
Wallace	F	4 yrs.	L: 17.0	15.5	8.60	7.80	0.51
Tulloch	F	4 yrs.	AP: 13.2	12.6	6.30	6.00	0.48
Frazer	F	4 yrs.	L: 17.0	15.5	7.20	6.60	0.42
Fairbairn	F	4 yrs.	L: 16.2	14.6	9.00	8.20	0.56
Wood	M	4 yrs.	AP: 14.5	13.8	7.00	6.65	0.48
Cruickshank	F	4yrs.4m.	AP: 15.5	14.8	8.50	7.70	0.55
Doig	F	4yrs.4m.	L: 16.5	15.2	7.50	6.80	0.45
Kerr	-	4yrs.6m.	L: 15.8	14.4	9.40	8.50	0.59
Nelson	M	4yrs.6m.	L: 18.9	17.2	8.00	7.30	0.42
Barnes	F	4yrs.6m.	AP: 17.0	16.2	7.35	7.00	0.43

GROUP 9 (5 years) (Range: $4\frac{1}{2}$ years to $5\frac{1}{2}$ years)

n = 24

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Kerr	-	4yrs.7m.	L: 16.5	14.9	9.50	8.55	0.58
Doig	F	4yrs.9m.	AP: 18.0	17.1	8.30	7.90	0.46
57	M	4yrs.9m.	(fresh)	17.0		8.50	0.50
Griffin	M	4yrs11m.	L: 17.0	15.5	8.90	8.00	0.52
Erskine	M	5 yrs.	L:17.9	16.1	8.80	7.95	0.49
Crighton	F	5 yrs.	L: 17.7	16.0	7.55	6.80	0.43
Thomson	-	5 yrs.	L: 17.0	15.3	8.60	7.75	0.51
Baillie	-	5 yrs.	L: 17.5	15.8	8.70	7.85	0.50
Craig	F	5 yrs.	L: 18.1	16.3	9.10	8.20	0.50
Hutchison	F	5 yrs.	AP: 15.5	14.7	8.50	8.10	0.55
Cruickshank	F	5 yrs.	AP: 18.0	17.1	8.00	7.60	0.44
Nelson	M	5 yrs.	AP: 19.0	18.1	7.70	7.35	0.41
Keith	M	5 yrs.	L: 16.7	15.0	9.25	8.30	0.55
Reed	F	5 yrs.	AP: 17.0	16.1	9.50	9.00	0.56
Boyle	M	5 yrs.	AP: 18.0	17.1	9.00	8.55	0.50
Wood	M	5 yrs.	AP: 17.0	16.1	8.40	8.00	0.49
Lukey	F	5 yrs.	L: 18.0	16.2	8.20	7.40	0.46
Bamford	F	5 yrs.	L: 18.0	16.2	8.10	7.30	0.45
Sneath	F	5 yrs.	L: 20.4	18.4	8.90	8.00	0.44
Park	M	5 yrs.	L: 18.2	16.4	7.75	7.00	0.43
Welsh	F	5 yrs.	L: 17.5	15.8	8.10	7.30	0.46
Stavely	F	5 yrs.	AP: 19.0	18.0	8.00	7.60	0.42
Shaw	M	$5\frac{1}{2}$ yrs.	L: 18.8	16.9	8.90	8.00	0.47
Keay	M	$5\frac{1}{2}$ yrs.	AP: 18.0	17.1	9.00	8.55	0.50

GROUP 10 (6 years) (Range: $5\frac{1}{2}$ years to $6\frac{1}{2}$ years)

n = 26

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Anderson	F	5yrs9m.	L: 19.1	17.2	8.55	7.70	0.45
Sutherland	M	6 yrs.	L: 20.5	18.4	9.45	8.50	0.46
Thomson	M	6 yrs.	L: 20.7	18.6	9.90	8.90	0.48
Rendall	F	6 yrs.	L: 18.0	16.2	9.50	8.55	0.53
McNicol	M	6 yrs.	L: 21.0	18.9	10.00	9.00	0.48
Baisden	F	6 yrs.	L: 17.3	15.6	8.50	7.65	0.49
Ross	F	6 yrs.	AP: 19.0	18.0	7.60	7.20	0.40
Pick	-	6 yrs.	L: 16.0	14.4	8.50	7.65	0.53
Anderson	M	6 yrs.	L: 19.5	17.6	8.75	7.90	0.45
Castle	M	6 yrs.	L: 17.5	15.7	10.50	9.45	0.60
Bogle	M	6 yrs.	L: 21.0	19.0	10.00	9.00	0.48
Wyse	M	6 yrs.	L: 20.0	18.0	9.50	8.55	0.48
Fraser	M	6 yrs.	L: 18.3	16.5	9.50	8.55	0.52
Ogilvie	M	6 yrs.	L: 18.0	16.2	10.50	9.45	0.58
Neilson	F	6 yrs.	L: 19.0	17.1	9.45	8.50	0.50
Gardner	F	6 yrs.	AP: 18.0	17.0	8.80	8.30	0.49
McNee	M	6 yrs.	L: 22,8	20.5	10.30	9.25	0.45
McGregor	M	6 yrs.	L: 17.2	15.5	10.90	9.80	0.63
Park	M	6 yrs.	AP: 18.5	17.5	8.00	7.60	0.43
Tucker	F	6 yrs.	L: 20.3	18.3	10.00	9.00	0.49
Clark	M	6 yrs.	L: 17.5	15.8	10.50	9.45	0.60
Imlach	M	6 yrs.	AP: 19.0	18.0	9.20	8.70	0.48
Golding	M	$6\frac{1}{2}$ yrs.	L: 18.5	16.7	9.25	8.30	0.50
Munro	F	$6\frac{1}{2}$ yrs.	L: 18.8	16.9	10.10	9.10	0.54
McNeil	M	$6\frac{1}{2}$ yrs.	AP: 18.2	17.2	9.30	8.80	0.51
Armstrong	F	$6\frac{1}{2}$ yrs.	L: 19.0	17.1	10.50	9.40	0.55

GROUP 11 (7 years) (Range: $6\frac{1}{2}$ years to $7\frac{1}{2}$ years)

n = 24

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Armstrong	F	7 yrs.	AP: 20.0	18.8	10.50	9.85	0.53
Glancy	F	7 yrs.	L: 17.9	16.0	8.55	7.70	0.48
Miller	M	7 yrs.	L: 19.0	17.0	11.00	9.85	0.58
Hamilton	M	7 yrs.	L: 20.5	18.4	11.00	9.85	0.54
Burns	F	7 yrs.	L: 19.6	17.6	10.45	9.40	0.53
Miller	-	7 yrs.	L: 19.5	17.5	10.05	9.00	0.52
Watson	F	7 yrs.	L: 18.7	16.7	9.80	8.75	0.52
Anderson	M	7 yrs.	L: 20.5	18.4	9.50	8.50	0.46
Griffen	M	7 yrs.	L: 19.0	17.0	9.00	8.10	0.47
Jappie	M	7 yrs.	L: 21.0	18.9	10.50	9.40	0.50
Nelson	M	7 yrs.	L: 20.1	18.0	9.10	8.15	0.45
Wilkie	M	7 yrs.	L: 19.1	17.1	9.75	8.70	0.51
Weir	F	7 yrs.	L: 17.0	15.2	8.50	7.60	0.50
59	F	7 yrs.	(fresh)	16.2		8.20	0.51
Tucker	F	7 yrs.	L: 21.0	18.8	11.30	10.10	0.54
Munro	F	7 yrs.	L: 20.7	18.5	11.70	10.40	0.57
Tulloch	F	7 yrs.	AP: 17.5	16.5	7.70	7.25	0.44
Kernaghan	F	7 yrs.	L: 20.0	17.9	10.20	9.10	0.51
Angus	F	7 yrs.	L: 19.0	17.0	8.80	7.90	0.46
Hunter	M	7 yrs.	L: 16.9	15.1	9.50	8.50	0.56
Forrest	M	7 yrs.	AP: 17.6	16.6	9.30	8.80	0.53
Marr	F	7 yrs.	AP: 16.5	15.5	9.00	8.50	0.55
Whytock	M	7 yrs.	L: 18.3	16.4	10.10	9.00	0.55
Denholm	M	7 yrs.	L: 19.0	17.0	10.40	9.30	0.55

GROUP 12 (8 years) (Range: $7\frac{1}{2}$ years to $8\frac{1}{2}$ years)

n = 25

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
McCue	M	8 yrs.	L: 24.5	21.8	12.00	10.70	0.49
Leslie	M	8 yrs.	L: 18.0	16.0	11.00	9.80	0.61
Dept. X-ray	-	8 yrs.	L: 20.0	17.8	9.40	8.35	0.47
Leslie	F	8 yrs.	L: 18.5	16.7	11.00	9.80	0.59
Kado-binskyvi	F	8 yrs.	AP: 18.5	17.5	9.00	8.50	0.49
Barnes	M	8 yrs.	L: 20.5	18.3	9.00	8.00	0.44
Smith	M	8 yrs.	L: 23.0	20.5	10.50	9.40	0.46
Skirving	M	8 yrs.	L: 21.7	19.5	10.05	8.95	0.46
Wright	M	8 yrs.	L: 20.0	17.8	10.20	9.10	0.51
Listard	M	8 yrs.	AP: 18.0	17.0	8.50	8.00	0.47
Kernaghan	F	8 yrs.	AP: 20.0	18.8	11.00	10.35	0.55
Barber	M	8 yrs.	AP: 20.0	18.8	9.95	9.40	0.50
Gray	M	8 yrs.	AP: 19.7	18.6	9.70	9.15	0.49
Triplett	M	8 yrs.	AP: 19.0	18.0	9.90	9.35	0.52
Hughes	M	8 yrs.	L: 20.2	18.0	10.00	8.90	0.50
McGrue	F	8 yrs.	AP: 20.0	18.8	10.50	9.90	0.53
Hamilton	F	8 yrs.	AP: 20.7	19.5	11.00	10.35	0.53
Scougall	M	8 yrs.	AP: 19.2	18.0	10.00	9.40	0.52
Muirhead	M	8 yrs.	AP: 17.0	16.0	9.20	8.65	0.54
Strang	M	8 yrs.	AP: 18.0	17.0	9.50	9.00	0.53
Frazer	M	8 yrs.	AP: 19.0	17.9	9.50	9.00	0.50
Staveley	F	8 yrs.	L: 22.6	20.0	9.60	8.45	0.42
Baxter	M	8 yrs.	AP: 19.0	17.9	10.00	9.40	0.53
Donaldson	F	8 yrs.	AP: 18.0	16.9	9.95	9.35	0.55
Wilson	F	8 yrs.	AP: 19.5	18.3	10.70	10.05	0.55

GROUP 13 (9 years) (Range: $8\frac{1}{2}$ years to $9\frac{1}{2}$ years)

n = 18

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Martindale	F	9 yrs.	L: 22.8	20.2	9.50	8.40	0.42
McFarlane	–	9 yrs.	L: 23.0	20.5	9.00	8.00	0.39
Symons	F	9 yrs.	L: 21.0	18.6	10.55	9.35	0.50
Millar	M	9 yrs.	L: 21.5	19.0	10.00	8.85	0.47
Stoddart	F	9 yrs.	L: 21.5	19.0	8.80	7.80	0.41
Harvey	F	9 yrs.	L: 20.2	18.0	10.50	9.35	0.52
Forrest	–	9 yrs.	L: 22.0	19.5	9.80	8.65	0.45
110359	–	9 yrs.	L: 21.0	19.0	8.65	7.65	0.41
Elder	M	9 yrs.	L: 22.5	20.0	10.00	8.85	0.44
Tait	M	9 yrs.	L: 24.0	21.5	10.15	9.00	0.42
McMillan	F	9 yrs.	L: 21.7	19.3	10.70	9.45	0.49
Hunter	M	9 yrs.	L: 20.5	18.2	10.50	9.30	0.51
Whittaker	F	9 yrs.	L: 20.5	18.2	10.20	9.05	0.50
Outerson	F	9 yrs.	AP: 19.5	18.3	10.40	9.80	0.53
Stewart	M	9 yrs.	AP: 18.2	17.1	10.00	9.40	0.55
Butterfield	F	9 yrs.	AP: 21.1	19.8	11.00	10.35	0.52
Brown	M	9 yrs.	L: 20.0	17.7	10.70	9.45	0.54
Donaldson	F	9 yrs.	AP: 20.5	19.3	11.30	10.60	0.55

GROUP 14 (10 years) (Range: $9\frac{1}{2}$ years to $10\frac{1}{2}$ years)

n = 18

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Wilson	F	10 yrs.	L: 24.5	21.6	11.10	9.80	0.45
Cunningham	F	10 yrs.	L: 22.0	19.4	10.50	9.20	0.48
Clark	–	10 yrs.	L: 23.5	20.7	10.00	8.80	0.43
McDonald	–	10 yrs.	L: 23.0	20.2	11.00	9.70	0.48
Murray	F	10 yrs.	L: 24.5	21.6	9.30	8.20	0.38
Bruce	F	10 yrs.	L: 22.5	19.8	12.00	10.55	0.53
Ellwood	F	10 yrs.	L: 23.5	20.7	11.00	9.70	0.47
Gray	M	10 yrs.	L: 23.5	20.7	10.50	9.25	0.45
Hannan	F	10 yrs.	L: 22.5	19.8	11.00	9.70	0.49
Smith	M	10 yrs.	L: 21.6	19.0	11.00	9.70	0.51
Patterson	M	10 yrs.	L: 21.0	18.5	11.00	9.70	0.52
Anderson	M	10 yrs.	L: 21.5	18.9	11.50	10.10	0.53
Watson	F	10 yrs.	AP: 20.7	19.5	11.00	10.35	0.53
Welsh	F	10 yrs.	L: 24.0	21.1	9.55	8.40	0.40
Laffey	F	10 yrs.	L: 23.2	20.4	10.50	9.25	0.45
Fowler	M	10 yrs.	AP: 19.0	17.9	10.00	9.40	0.53
Black	F	10 yrs.	AP: 23.5	22.1	9.50	8.95	0.40
Gibb	F	10 yrs.	AP: 22.0	20.7	10.00	9.40	0.45

GROUP 15 (11 and 12 years) (Range: $10\frac{1}{2}$ to $12\frac{1}{2}$ years)

n = 26

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Smith	F	11 yrs.	L: 25.0	21.9	11.70	10.25	0.47
Rogers	F	11 yrs.	AP: 23.0	21.5	11.00	10.30	0.48
Kirby	F	11 yrs.	L: 27.0	23.6	11.60	10.15	0.43
Wightman	M	11 yrs.	L: 21.0	18.4	10.00	8.75	0.48
Hazlett	F	11 yrs.	L: 24.0	21.0	12.00	10.50	0.50
Bruce	F	11 yrs.	L: 24.0	21.0	12.00	10.50	0.50
Fowler	M	11 yrs.	L: 21.5	18.8	11.30	9.90	0.53
Cosgrove	-	11 yrs.	L: 24.0	21.0	12.00	10.50	0.50
Anderson	M	11 yrs.	L: 24.0	21.0	10.00	8.75	0.42
Shakespeare	M	11 yrs.	L: 23.0	20.1	12.00	10.50	0.52
Barber	F	11 yrs.	AP: 21.0	19.6	11.30	10.55	0.54
Crowe	-	11 yrs.	L: 23.5	20.6	12.20	10.70	0.52
Lindsay	M	11 yrs.	AP: 21.0	19.6	11.80	11.05	0.56
Stephen	F	$11\frac{1}{2}$yrs.	L: 27.0	23.6	10.50	9.20	0.39
Fegan	-	$11\frac{1}{2}$yrs.	L: 24.5	21.4	11.00	9.65	0.45
Tait	F	11yrs7m.	L: 24.0	20.9	11.50	10.00	0.48
Horsfall	M	11yrs8m.	L: 26.0	22.6	12.00	10.50	0.46
Anderson	M	12 yrs.	L: 26.0	22.6	12.00	10.50	0.46
Naves	F	12 yrs.	L: 26.0	22.6	11.20	9.75	0.43
Wishart	M	12 yrs.	L: 25.2	21.9	13.00	11.30	0.52
McDonald	F	12 yrs.	L: 23.0	20.0	10.20	8.85	0.44
Ellwood	F	12 yrs.	L: 29.0	25.2	12.50	11.00	0.43
Heveron	M	12 yrs.	L: 23.0	20.0	10.30	8.95	0.45
Thayne	F	12 yrs.	AP: 23.0	21.4	11.50	10.70	0.50
Dept.X-ray	-	12 yrs.	L: 24.0	20.9	11.80	10.25	0.49
Sargant	F	12 yrs.	L: 24.0	20.9	11.50	10.00	0.48

GROUP 16 (13 and 14 years)

n = 7

Specimen or Name	Sex	Age	Vertebral Body		'Total Disc'		Index Disc/V.B.
			A	B	A	B	
Davidson	M	13 yrs.	L: 26.0	22.5	11.00	9.55	0.42
Anderson	M	13 yrs.	L: 29.0	25.1	12.50	10.85	0.43
Tait	F	13 yrs.	L: 32.0	27.7	13.50	11.70	0.42
Thayne	F	13 yrs.	AP: 24.5	22.8	11.80	11.00	0.48
Wishart	M	13yrs10m.	L: 26.0	22.5	12.50	10.85	0.48
Glen-dinning	F	14 yrs.	L: 30.0	26.0	11.00	9.55	0.37
Mullen	F	14 yrs.	L: 27.0	23.4	12.20	10.55	0.45

GROUP 17 Adults.

n = 11

			L: 32.0	27.2	13.00	11.05	0.41
			L: 37.0	31.5	12.30	10.50	0.33
			L: 32.0	27.2	12.50	10.65	0.39
			L: 31.0	26.4	12.00	10.20	0.39
			L: 32.0	27.2	13.00	11.05	0.41
			L: 30.0	25.5	13.50	11.50	0.45
			L: 30.0	25.5	13.00	11.05	0.43
			L: 31.0	26.4	13.00	11.05	0.42
			L: 29.5	25.1	12.80	10.90	0.43
			L: 33.0	28.0	13.80	11.75	0.42
			L: 37.0	31.5	14.00	11.90	0.38

Appendix to Table 8a

'Total Disc' Heights: Postmortem Discs

(includes additional 'total disc' data for which no corresponding 'vertebral body' heights are available)

Case No.	Age	'Total Disc' A	'Total Disc' B	Mean	Standard Deviation
37 M	1 m.	3.40	3.60		
38 M	2 m.	4.30	4.55		
39 M	3½m.	3.75	4.00		
40 M	3½m.	3.70	3.90		
41 M	4 m.	4.40	4.65	4.32	0.46
42 M	4 m +	4.50	4.75		
43 M	5 m.	4.60	4.90		
44 M	6 m.	-	4.20		
45 F	10 m.	-	5.00	5.05	-
46 M	14 m.	-	5.10		
48 F	1.8/12 yrs.	3.90	4.15		
49 M	2 yrs.	4.60	4.90	4.56	0.32
50 F	2 yrs.	4.40	4.70		
51 M	2.3/12 yrs.	4.25	4.50		
52 F	2.8/12 yrs.	-	5.90		
53 F	3 yrs.	6.50	6.90	6.34	0.54
54 F	3.4/12 yrs.	5.50	5.85		
55 M	3.9/12 yrs.	6.30	6.70		
57 M	4.9/12 yrs.	-	8.50		
58 M	5 yrs.	9.50	10.05	8.92	0.99
59 F	7.6/12 yrs.	-	8.20		

Table 8a

Means and Standard Deviations for Groups 1-17

(i) All cases

Group No.	No. of Cases	Mean Age	L4-5 Mean 'Total Disc'	Standard Deviation	L4 Mean 'V.B.'	Standard Deviation	Mean Index Disc/V.B.	Standard Deviation
1	10	32 w.	3.30mm.	0.38mm.	4.97mm.	0.69mm.	0.67	0.09
2	17	40 w.	3.94mm.	0.52mm.	7.35mm.	0.79mm.	0.54	0.08
3	27	3.5.m.	4.14mm.	0.44mm.	9.84mm.	0.44mm.	0.42	0.09
4	20	9.0 m.	4.37mm.	0.43mm.	11.50mm.	0.74mm.	0.38	0.04
5	19	15.2 m.	4.98mm.	0.51mm.	12.58mm.	0.74mm.	0.40	0.04
6	32	2yrs.1m.	5.24mm.	0.63mm.	13.70mm.	0.92mm.	0.38	0.04
6a	9	1yr. 9m.	5.14mm.	0.57mm.	13.64mm.	0.96mm.	0.36	0.03
6b	11	2 yrs.	5.35mm.	0.46mm.	13.42mm.	0.47mm.	0.40	0.03
6c	12	2yrs.4.6m.	5.45mm.	0.70mm.	14.00mm.	1.06mm.	0.39	0.05
7	25	3 yrs.	6.39mm.	0.57mm.	14.60mm.	0.86mm.	0.44	0.04
8	25	4 yrs.	7.21mm.	0.73mm.	15.20mm.	0.93mm.	0.48	0.06
9	24	5 yrs.	7.90mm.	0.54mm.	16.38mm.	0.99mm.	0.48	0.05
10	26	6 yrs.	8.63mm.	0.69mm.	17.23mm.	1.33mm.	0.50	0.05
11	24	7 yrs.	8.83mm.	0.84mm.	17.17mm.	1.13mm.	0.52	0.04
12	25	8 yrs.	9.25mm.	0.71mm.	18.22mm.	1.35mm.	0.51	0.04
13	18	9 yrs.	9.08mm.	0.78mm.	19.07mm.	1.09mm.	0.48	0.05
14	18	10 yrs.	9.45mm.	0.61mm.	20.14mm.	1.14mm.	0.47	0.05
15	26	11.4 yrs.	10.12mm.	0.72mm.	21.23mm.	1.52mm.	0.48	0.04
16	7	13.4 yrs.	10.58mm.	0.79mm.	24.29mm.	2.03mm.	0.44	0.04
17	11	Adults	11.05mm.	0.51mm.	27.41mm.	2.20mm.	0.41	0.03

(6a = cases under 2 years; 6b = cases at 2 years: 6c = cases over 2 years)

Table 8a

Means and Standard Deviations for Groups 1-16

(ii) Comparison of Males and Females

Group No.	M or F	No. of Cases	Mean Age	L4-5 Mean 'Total Disc'	Standard Deviation	L4 Mean 'V.B.'	Standard Deviation	Mean Index Disc/V.B.	Standard Deviation
1	M	6	32.7w.	3.33mm.	0.38mm.	5.08mm.	0.54mm.	0.66	0.10
	F	5	30.3w.	3.26mm.	0.43mm.	4.83mm.	1.00mm.	0.69	0.07
2	M	9	40 w.	4.00mm.	0.60mm.	7.62mm.	0.86mm.	0.53	0.09
	F	5	40 w.	3.98mm.	0.50mm.	7.06mm.	0.68mm.	0.57	0.08
3	M	12	3.8m.	4.16mm.	0.40mm.	9.88mm.	1.10mm.	0.42	0.07
	F	11	3.5m.	4.00mm.	0.46mm.	9.57mm.	0.75mm.	0.42	0.05
4	M	7	9.1m.	4.46mm.	0.42mm.	11.86mm.	0.81mm.	0.38	0.05
	F	10	8.9m.	4.39mm.	0.45mm.	11.28mm.	0.64mm.	0.38	0.04
5	M	10	15.6m.	5.05mm.	0.57mm.	12.88mm.	0.49mm.	0.39	0.04
	F	6	15.3m.	4.78mm.	0.24mm.	12.30mm.	0.93mm.	0.39	0.03
6	M	17	2yrs. 1m.	5.38mm.	0.48mm.	13.76mm.	0.87mm.	0.39	0.04
	F	13	2yrs. 1m.	5.12mm.	0.76mm.	13.60mm.	1.06mm.	0.38	0.04
7	M	10	3yrs.0.3m	6.40mm.	0.66mm.	14.60mm.	0.81mm.	0.44	0.03
	F	11	2yrs.11m.	6.30mm.	0.45mm.	14.50mm.	0.92mm.	-	-
8	M	8	4yrs.	7.26mm.	0.80mm.	15.49mm.	1.05mm.	0.47	0.06
	F	15	4yrs.0.4m	7.07mm.	0.67mm.	15.11mm.	1.01mm.	0.47	0.05
9	M	10	5yrs.0.8m	8.02mm.	0.51mm.	16.53mm.	0.90mm.	0.49	0.04
	F	11	5yrs.0.3m	7.75mm.	0.59mm.	16.54mm.	1.05mm.	0.47	0.05
10	M	16	6yrs.1m.	8.83mm.	0.59mm.	17.51mm.	1.40mm.	0.51	0.06
	F	9	6yrs.0.8m	8.38mm.	0.74mm.	17.47mm.	1.15mm.	0.49	0.05
11	M	11	7yrs.	8.92mm.	0.62mm.	17.26mm.	1.09mm.	0.52	0.04
	F	12	7yrs.	8.73mm.	1.05mm.	17.06mm.	1.26mm.	0.51	0.04
12	M	16	8yrs.	9.14mm.	0.64mm.	18.19mm.	1.49mm.	0.50	0.04
	F	8	8yrs.	9.59mm.	0.76mm.	18.31mm.	1.19mm.	0.53	0.05

Table 8a (contd.)

Means and Standard Deviations for Groups 1-16

(ii) Comparison of Males and Females

Group No.	M or F	No. of Cases	Mean Age	L4-5 Mean 'Total Disc'	Standard Deviation	L4 Mean 'V.B.'	Standard Deviation	Mean Index Disc/V.B.	Standard Deviation
13	M	6	9yrs.	9.14mm.	0.27mm.	18.92mm.	1.62mm.	0.49	0.05
	F	9	9yrs.	9.36mm.	0.86mm.	18.97mm.	0.75mm.	0.49	0.05
14	M	5	10yrs.	9.63mm.	0.33mm.	19.00mm.	1.04mm.	0.51	0.03
	F	11	10yrs.	9.41mm.	0.73mm.	20.61mm.	0.92mm.	0.46	0.05
15	M	9	11yrs.4.9m	10.02mm.	0.99mm.	20.56mm.	1.56mm.	0.49	0.05
	F	13	11yrs.5.6m	10.13mm.	0.60mm.	21.78mm.	1.58mm.	0.47	0.04
16	M	3	13yrs.3m.	10.42mm.	0.75	23.37	1.50mm.	0.45	0.04
	F	4	13yrs.6m.	10.70mm.	0.90	24.98	2.29mm.	0.43	0.04

TABLE 8a

Means and Standard Deviations for Groups 1-10

(iii) Comparison of X-ray and Postmortem measurements
('Total Disc' only)

Group No.	X-ray and Postmortem	No. of Cases	Mean Age	Mean 'Total Disc'	Standard Deviation
1	X-ray	–	–	–	–
	Postmortem	10	32w.	3.30mm.	0.38mm.
2	X-ray	8	40w.	3.68mm.	0.33mm.
	Postmortem	10	40w.	4.11mm.	0.59mm.
3	X-ray	22	4.0m.	4.15mm.	0.46mm.
	Postmortem *	8	3.5m.	4.32mm.	0.46mm.
4	X-ray	19	8.7m.	4.35mm.	0.44mm.
45, 46	Postmortem *	2	12m.	5.05mm.	5.10mm.
5	X-ray	18	15.2m.	4.97mm.	0.53mm.
6	X-ray	29	2yrs.	5.33mm.	0.60mm.
	Postmortem *	4	2yrs.	4.56mm.	0.32mm.
7	X-ray	23	3yrs.	6.38mm.	0.58mm.
	Postmortem *	4	3yrs2m.	6.34mm.	0.54mm.
8	X-ray	25	4yrs0.6m	7.21mm	0.73mm.
9	X-ray	23	5 yrs.	7.87mm.	0.53mm.
10	X-ray	26	6 yrs.	8.63mm.	0.69mm.
57, 58, 59	Postmortem *	3	5yrs.9m.	8.92mm.	0.99mm.

* (See appendix to Table 8a (page 88))

Means for Vertebral Body Height at 40 weeks:

X-ray cases (n = 7) mean = 7.7 ± 0.9

Postmortem cases (n = 10) mean = 7.1 ± 0.6

Table 8a

Statistical Comparison of Lumbar Indices

(iv)

	Group No.	No. of Cases	Mean Age	Mean Index	S.D.	Student t	P
All Cases	1	10	32 w.	0.67	0.09	-	-
	2	17	40 w.	0.54	0.08	3.76	< 0.001
	3	27	3.5m.	0.42	0.04	6.52	< 0.001
	4	20	9.0m.	0.38	0.04	3.54	< 0.001
	6	32	2yrs.1m.	0.38	0.04		
	7	25	3 yrs.	0.44	0.04	5.26	< 0.001
	8	25	4 yrs.	0.48	0.05	2.76	< 0.01
	11&12	49	7½yrs.	0.51	0.05	3.14	< 0.005
	17	11	Adults	0.41	0.03	7.96	< 0.001
X-ray Cases	2	7	40 w.	0.49	0.04		
	3	22	3.7m.	0.42	0.04	3.61	< 0.005
	6	29	2 yrs.	0.39	0.04	2.71	< 0.01
	7	23	3 yrs.	0.44	0.04	4.64	< 0.001
	8	25	4 yrs.	0.48	0.05	2.93	< 0.005
	11&12	49	7½ yrs.	0.51	0.05	3.14	< 0.005
Postmortem Cases	1	10	32 w.	0.67	0.09		
	2	9	40 w.	0.58	0.09	2.31	< 0.05
	3	5	3.5m.	0.43	0.03	3.70	< 0.005
	6	3	2 yrs.	0.36	0.04	3.19	< 0.02
	52,53 57,59	4	4½ yrs.	0.49	0.04	4.19	< 0.01

(The mean indices of successive groups are compared)

TABLE 8b

HEIGHTS OF VERTEBRAL BODY - T 8 and of INTERVERTEBRAL DISC - T 8-9

GROUP 1 (Premature foetuses) n = 6

Specimen or Name	Sex	Age	Vertebral Body		'Total Disc'		Index Disc/V.B.
			A	B	A	B	
4	F	29wks.	AP: 3.3	3.50	2.40	2.55	0.73
6	M	30wks.	3.5	3.70	2.40	2.55	0.69
7	M	30wks.	3.4	3.60	2.30	2.45	0.68
14	M	34wks.	3.9	4.15	2.30	2.45	0.59
16	F	35wks.	4.4	4.65	2.40	2.55	0.55
17	M	35wks.	3.9	4.15	2.80	2.95	0.72

GROUP 2 (Full term foetuses) n = 11

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
20	F	40wks.	4.7	5.0	3.20	3.40	0.68
21	F	40wks.	5.0	5.3	2.50	2.65	0.50
22	M	40wks.	5.0	5.3	3.30	3.50	0.66
23	F	40wks.	4.6	4.9	3.30	3.50	0.72
24	M	40wks.	5.4	5.7	3.00	3.20	0.56
Dept.X-rayI	-	40wks.	L: 5.6	5.4	3.30	3.50	0.59
Brogan	M	40wks.	L: 6.0	5.8	2.80	2.70	0.47
McKenzie	M	40wks.	L: 6.4	6.1	3.00	2.90	0.47
Charles	F	40wks.	L: 6.0	5.8	2.40	2.30	0.40
Tait	M	40wks.	AP: 5.0	4.9	3.00	2.95	0.60
Welsh	F	40wks.	L: 5.0	4.8	2.75	2.65	0.55

GROUP 3 (1 to 6 months) n = 22

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
McFadden	M	1 month	AP: 7.0	6.8	3.50	3.40	0.50
Lamb	F	$1\frac{1}{2}$months	AP: 6.7	6.5	3.20	3.10	0.48
Myles	-	2 months	L: 7.2	6.9	3.10	2.95	0.43
Rae	F	2 months	AP: 7.2	7.0	3.10	3.05	0.43
Van Gelder	F	2 months	AP: 6.8	6.6	3.45	3.35	0.51
Walker	F	3 months	L: 6.8	6.4	3.60	3.40	0.53
Sneddon	F	3 months	L: 6.5	6.2	3.15	3.00	0.48
40	M	$3\frac{1}{2}$months		7.1		2.90	0.41
42	M	4 months	L: 6.0	6.4	3.40	3.60	0.57
McLarty	F	4 months	AP: 7.0	6.8	3.40	3.30	0.49
Medlock	F	5 months	AP: 8.5	8.2	3.25	3.15	0.38
43	M	5 months	L: 7.0	7.4	3.50	3.70	0.50
J. Brown	-	5 months	L: 8.3	7.8	4.05	3.80	0.44
Ross	F	5 months	AP: 6.7	6.5	4.00	3.90	0.60
Murtagh	M	5 months	L: 7.4	7.0	4.05	3.80	0.55
Lear	F	5 months	L: 8.0	7.5	2.80	2.65	0.35
Brown	M	5 months	L: 7.1	6.7	2.80	2.65	0.39
Campbell	F	5 months	L: 8.5	8.0	3.00	2.85	0.35
Hanlon	M	5 months	AP: 8.0	7.8	3.50	3.40	0.44
Ferris	M	5 months	AP: 7.3	7.1	3.50	3.40	0.48
Lorimer	M	6 months	AP: 7.8	7.6	3.60	3.50	0.46
Van Gelder	F	6 months	AP: 7.4	7.2	3.85	3.75	0.52

GROUP 4 (7 to 12 months) n = 13.

Specimen or Name	Sex	Age	Vertebral Body			'Total Disc'		Index Disc/V.B.
				A	B	A	B	
Borthwick	F	7 m.	L:	8.2	7.7	4.00	3.75	0.44
Cruickshank		8 m.	AP:	7.9	7.6	3.10	3.00	0.39
Tait	M	8 m.	L:	8.2	7.7	3.20	3.00	0.39
Cunningham	F	8 m.	AP:	7.5	7.3	3.25	3.15	0.43
Findlay	F	8 m.	L:	8.7	8.1	3.65	3.40	0.42
McKay		9 m.	L:	9.2	8.6	3.60	3.35	0.39
Welsh	F	9 m.	L:	8.9	8.3	3.10	2.90	0.35
Borthwick	F	9 m.	L:	8.9	8.3	3.80	3.55	0.43
Morrison	M	9 m.	L:	8.8	8.2	3.20	3.00	0.36
McFadden	M	10 m.	L:	9.2	8.6	3.90	3.65	0.42
Beck	M	11 m.	L:	8.6	8.0	3.60	3.35	0.42
McFarfane	M	11 m.	AP:	9.5	9.2	3.80	3.65	0.40
Smith		12 m.	L:	8.6	8.0	4.20	3.90	0.49

GROUP 5 (13 to 18 months) n = 16.

Specimen or Name	Sex	Age	Vertebral Body			'Total Disc'		Index Disc/V.B.
				A	B	A	B	
Gillies	M	13 m.	L:	10.4	9.7	4.00	3.70	0.38
Reid	F	13 m.	L:	12.0	11.2	3.50	3.25	0.29
Findlay	F	13 m.	AP:	9.0	8.7	3.50	3.40	0.39
46	M	14 m.	SS:	8.4	8.9	3.20	3.40	0.38
Stevenson	M	14 m.	L:	10.0	9.3	3.95	3.65	0.40
Brown	–	15 m.	L:	9.5	8.8	4.10	3.80	0.43
Brunton		15 m.	L:	10.0	9.3	3.80	3.55	0.38
Patterson	M	15 m.	L:	10.6	9.9	3.25	3.00	0.31
Sinclair	M	16 m.	L:	10.2	9.5	3.60	3.35	0.35
Wood	M	17 m.	L:	9.6	8.9	3.80	3.50	0.40
Ross	F	17 m.	AP:	8.8	8.5	3.70	3.55	0.42
Scally	M	18 m.	L:	10.5	9.7	4.20	3.90	0.40
Tait	M	18 m.	L:	10.9	10.1	3.35	3.10	0.31
Rafferty	F	18 m.	L:	9.0	8.3	3.60	3.35	0.40
Judge	F	18 m.	AP:	9.2	8.9	3.80	3.65	0.41
McFarlane	M	18 m.	AP:	10.5	10.1	3.80	3.65	0.36

GROUP 6 (1 year 7 months to 2 years 6 months) n= 24

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Brown	F	1yr.7m.	AP: 9.0	8.7	3.50	3.35	0.39
Hunter	M	1yr.7m.	AP: 10.0	9.6	3.70	3.55	0.37
Norris	M	1yr.8m.	AP: 10.2	9.8	3.20	3.10	0.31
Keith	F	1yr.9m.	L: 9.6	8.9	3.30	3.05	0.34
Tait	M	1yr.9m.	L: 10.8	10.0	3.50	3.25	0.32
Wilson	M	1yr.9m.	AP: 8.7	8.4	3.35	3.20	0.39
Millar	F	1yr.10m.	L: 11.0	10.1	3.50	3.25	0.32
McFadden	M	1yr.10m.	AP: 10.0	9.6	4.00	3.85	0.40
McKendrick	F	2 years	AP: 10.9	10.5	3.60	3.45	0.33
Birrell	M	2 years	AP: 10.8	10.4	3.20	3.05	0.30
Brown	M	2 years	L: 10.2	9.4	3.35	3.10	0.33
Gillies	F	2 years	AP: 9.9	9.5	3.70	3.55	0.37
Kamara-valli	M	2yrs.1m.	L: 10.9	10.0	4.35	4.00	0.40
Davidson	F	2yrs.1m.	AP: 10.4	10.0	3.20	3.05	0.31
Rafferty	F	$2\frac{1}{2}$ years	L: 11.3	10.4	4.25	3.90	0.38
Wood	M	2yrs.3m.	AP: 9.1	8.7	3.65	3.50	0.40
Brunton		2yrs.3m.	L: 10.6	9.8	4.10	3.75	0.39
Lorimer	M	2yrs.3m.	AP: 11.2	10.8	3.70	3.55	0.33
Mason	F	2yrs.6m.	L: 10.5	9.6	3.15	2.90	0.30
Spiers	F	2yrs.6m.	L: 12.0	11.0	3.30	3.05	0.28
Barrow	M	2yrs.6m.	L: 12.5	11.5	3.25	3.00	0.26
Jones	F	2yrs.6m.	L: 13.0	11.9	3.25	3.00	0.25
Anderson	M	2yrs.6m.	L: 12.1	11.1	3.80	3.50	0.31
Ridgeway	M	2yrs.6m.	L: 12.7	11.7	3.50	3.20	0.28

GROUP 7 (2 years 7 months to 3 years 6 months) n = 15

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
52	F	2yrs.8m.	(fresh)	10.6		3.40	0.32
Bagwell	F	2yrs10m.	L: 11.9	10.9	4.25	3.90	0.36
Ross	F	2yrs11m.	AP: 11.5	11.0	3.50	3.35	0.30
Davies	M	3 years	L: 12.7	11.6	3.35	3.05	0.26
Virtue	F	3 years	L: 12.9	11.8	3.30	3.00	0.26
Robinson	M	3 years	L: 12.2	11.2	4.00	3.65	0.33
Rae	F	3 years	L: 9.2	8.5	3.90	3.60	0.42
Smith	M	3 years	AP: 11.1	10.6	3.70	3.55	0.33
Sinclair	M	3 years	L: 11.3	10.3	4.15	3.80	0.37
Stirling	F	3 years	L: 12.7	11.6	4.00	3.65	0.31
Ewart	M	3 years	L: 10.8	9.9	3.70	3.40	0.34
54	F	3yrs.4m.	SS: 8.8	9.3	4.35	4.60	0.49
McKay	M	3yrs.4m.	AP: 12.5	12.0	3.50	3.35	0.28
Rafferty	F	3yrs.6m.	L: 11.8	10.8	4.00	3.65	0.34
Knight	M	3yrs.6m.	AP: 12.8	12.2	3.90	3.75	0.30

GROUP 8 (3 years 7 months to 4 years 6 months). n = 16

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
55	M	3yrs9m.	SS: 11.0	11.7	3.10	3.30	0.28
Tait	M	3yrs9m.	L: 15.0	13.6	3.60	3.30	0.24
Tulloch	F	3yrs9m.	L: 10.5	9.6	3.80	3.45	0.36
Alcorn	M	3yrs9m.	AP: 12.1	11.5	3.70	3.55	0.31
Thomson	M	3yrs10m	L: 12.5	11.4	5.00	4.55	0.40
Park	M	3yrs11m	L: 13.2	12.0	3.85	3.50	0.29
Dept X-ray		4 yrs.	L: 13.2	12.0	3.45	3.15	0.26
Doig	F	4 yrs.	AP: 11.0	10.5	4.30	4.10	0.39
Brown	F	4 yrs.	L: 13.6	12.4	4.00	3.65	0.29
McFarlane	M	4 yrs.	L: 14.2	12.9	4.95	4.50	0.35
Wallace	F	4 yrs.	L: 13.8	12.5	4.65	4.25	0.34
Sinclair	M	4 yrs.	L: 12.0	10.9	4.25	3.85	0.35
Doig	F	4yrs3m.	AP: 11.2	10.7	4.20	4.00	0.38
McKay	M	4yrs4m.	AP: 13.0	12.4	3.50	3.35	0.27
Nelson	M	4yrs6m.	L: 13.7	12.4	4.70	4.25	0.34
Wood	M	4yrs6m.	AP: 11.5	11.0	3.80	3.65	0.33

GROUP 9 (4 years 7 months to 5 years 6 months) n = 16.

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
57	M	4yrs9m.	(fresh)	12.8		4.40	0.34
Beck	M	4yrs11m	L: 13.0	11.7	3.75	3.40	0.29
Ross	F	4yrs11m	AP: 12.5	11.9	3.80	3.60	0.30
Dept X-ray		5 yrs.	L: 14.4	13.0	4.20	3.80	0.29
Erskine	M	5 yrs.	L: 13.8	12.5	4.20	3.80	0.30
Gilzean	M	5 yrs.	AP: 12.5	11.9	3.50	3.35	0.28
Keith	F	5 yrs.	L: 13.0	11.7	3.50	3.15	0.27
Keith	M	5 yrs.	L: 12.7	11.5	4.45	4.00	0.35
Sinclair	M	5 yrs.	L: 12.5	11.3	4.30	3.90	0.34
Park	M	5 yrs.	L: 13.2	11.9	3.70	3.35	0.28
Rafferty	F	5 yrs.	L: 12.7	11.5	4.10	3.70	0.32
Saunders	F	5 yrs.	AP: 12.2	11.6	4.00	3.80	0.33
Reid	M	5 yrs.	L: 13.0	11.7	4.20	3.80	0.32
Wilson	M	5 yrs.	L: 11.3	10.2	3.40	3.10	0.30
Shaw	M	5yrs6m.	L: 15.6	14.0	4.00	3.60	0.26
Coleman	M	5 yrs.	L: 13.5	12.2	3.50	3.15	0.26

Group 10 (5 years 7 months to 6 years 6 months)

n = 14

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Ross	F	5yrs11m	AP: 13.0	12.3	3.60	3.40	0.28
Beck	M	5yrs11m	L: 13.8	12.4	3.65	3.30	0.26
Welsh	F	6 years	L: 13.6	12.2	5.00	4.50	0.37
Erskine	M	6 years	L: 14.2	12.7	4.20	3.75	0.30
Thomson	M	6 years	L: 14.5	13.0	4.70	4.20	0.32
Sutherland	M	6 years	L: 14.5	13.0	5.00	4.50	0.34
Meehan	M	6 years	L: 13.0	11.7	3.90	3.50	0.30
Neilson	F	6 years	L: 15.9	14.3	5.30	4.75	0.33
Brown	M	6 years	AP: 14.2	13.5	3.45	3.25	0.24
Barber	M	6 years	L: 14.7	13.2	4.10	3.70	0.28
Sinclair	M	6 years	L: 13.0	11.7	4.45	4.00	0.34
Rafferty	F	6 years	L: 13.4	12.0	4.20	3.75	0.31
Whytock	M	6yrs 3m	AP: 13.5	12.8	4.20	4.00	0.31
Munro	F	6yrs 6m	L: 16.0	14.3	4.10	3.65	0.26

Group 11 (7 years and 8 years)

n = 20

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Smith	M	7 years	L: 13.8	12.3	4.35	3.90	0.32
Glancy	F	7 years	L: 16.5	14.7	4.20	3.75	0.25
Barber	M	7 years	L: 15.0	13.4	4.25	3.80	0.28
Kernaghan	F	7 years	L: 14.7	13.1	4.75	4.25	0.32
Rafferty	F	7 years	L: 13.9	12.4	4.20	3.75	0.30
Angus	F	7 years	L: 14.0	12.5	4.00	3.55	0.29
Hunter	M	7 years	AP: 13.0	12.3	4.45	4.20	0.34
Weir	F	7 years	L: 12.5	11.2	4.50	4.00	0.36
59	F	7yrs 6m	(fresh)	13.0		4.50	0.35
Kadobin-skyvi	F	7yrs 6m	L: 14.1	12.6	3.60	3.20	0.26
Thomson	M	7yrs.6m	L: 16.5	14.7	4.50	4.00	0.27
Dept. X-ray		8 years	L: 16.9	15.0	4.50	4.00	0.27
Wilson	F	8 years	AP: 16.3	15.4	4.40	4.15	0.27
Leslie	F	8 years	L: 15.9	14.1	4.95	4.40	0.31
Stewart	F	8 years	L: 17.5	15.6	4.15	3.70	0.24
Wright	M	8 years	L: 15.6	13.9	5.00	4.45	0.32
Listard	M	8 years	L: 14.8	13.2	4.05	3.60	0.27
Skirving	M	8 years	AP: 14.9	14.1	3.70	3.50	0.25
Barber	M	8 years	AP: 15.0	14.2	4.05	3.80	0.27
Baxter	F	8 years	AP: 14.5	13.7	4.60	4.35	0.32

GROUP 12 (9 years and 10 years) n = 19

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Kadobin-skyvi	F	9 years	L: 16.0	14.1	3.70	3.30	0.23
Resnick	M	9 years	AP: 16.0	15.1	4.80	4.50	0.30
Rafferty	F	9 years	L: 15.2	13.5	5.40	4.75	0.36
Barber	M	9 years	L: 18.0	15.9	4.50	4.00	0.25
Hunter	M	9 years	L: 16.7	14.8	4.10	3.60	0.25
Pollock	F	9yrs 6m	L: 13.8	12.2	5.70	5.00	0.41
Smith	M	9yrs 6 m	L: 15.0	13.3	5.40	4.75	0.36
Fuchs	M	10 yrs.	L: 17.0	15.0	5.10	4.50	0.30
Laffey	F	10 yrs.	L: 16.6	14.6	5.50	4.85	0.33
Kadobin-skyvi	F	10 yrs.	AP: 16.0	15.0	3.70	3.50	0.23
Horsfall	M	10 yrs.	L: 17.0	15.0	5.00	4.40	0.29
Gray	M	10 yrs.	L: 20.0	17.6	5.00	4.40	0.25
McDonald	M	10 yrs.	L: 17.0	15.0	4.80	4.20	0.28
Hannan	F	10 yrs.	L: 20.0	17.6	5.20	4.60	0.26
Dobbie	F	10 yrs.	L: 16.0	14.1	5.45	4.80	0.34
Sinclair	M	10 yrs.	L: 14.9	13.1	4.65	4.10	0.31
Park	M	10 yrs.	L: 16.0	14.1	4.00	3.50	0.25
Welsh	F	10 yrs.	L: 18.0	15.8	5.00	4.40	0.28
Stoddart	F	10yrs6m	L: 17.0	15.0	4.55	4.00	0.27

GROUP 13 (11 years and 12 years) n = 12

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Kadobin-skyvi	F	11 yrs.	AP: 17.0	16.0	4.00	3.75	0.24
Shakespeare	M	11 yrs.	L: 18.3	16.0	5.00	4.40	0.27
McPhillips	F	11 yrs.	L: 20.0	17.5	5.75	5.05	0.29
Crawley	M	11 yrs.	L: 20.0	17.5	5.50	4.80	0.28
Welsh	F	11 yrs.	L: 18.6	16.3	5.35	4.70	0.29
Ritchie		11yrs6m	L: 20.0	17.5	5.00	4.40	0.25
Tait	F	11yrs7m	L: 21.0	18.3	6.30	5.50	0.30
Welsh	F	12 yrs.	L: 22.0	19.1	6.00	5.20	0.27
Millington	F	12 yrs.	L: 20.7	18.0	6.80	5.90	0.33
Hughes	F	12 yrs.	L: 16.3	14.2	6.05	5.25	0.37
Rafferty	F	12 yrs.	L: 16.6	14.4	6.00	5.20	0.36
Hughes	F	12yrs4m	L: 16.6	14.4	6.25	5.45	0.38

GROUP 14 (13 years and 14 years) n = 6

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Laing		13 yrs.	L: 22.5	19.5	6.50	5.60	0.21
Davidson		13 yrs.	L: 19.7	17.0	5.50	4.75	0.28
Jones		13yrs6m	L: 25.0	21.6	6.00	5.20	0.24
Welsh	F	14 yrs.	L: 23.0	19.8	6.40	5.50	0.28
Flanagan	14	14 yrs.	L: 23.0	19.8	7.00	6.00	0.30
Swinnock		14 yrs.	L: 20.2	17.4	5.50	4.75	0.27

GROUP 15 (Adults) n = 6

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
			L: 23.0	19.8	6.0	5.2	0.26
			AP: 20.5	19.2	5.9	5.1	0.29
			L: 22.8	19.6	6.1	5.3	0.27
			L: 24.0	22.7	6.0	5.2	0.25
			L: 22.0	19.0	5.5	4.7	0.25
			L: 22.5	19.5	6.0	5.2	0.27

Table 8b

Means and Standard Deviations for Groups 1-15

(i) All cases

Group No.	No. of Cases	Mean Age	T8-9 Mean 'Total Disc'	Standard Deviation	T8 Mean 'V.B.'	Standard Deviation	Mean Index Disc/V.B.	Standard Deviation
1	6	32 w.	2.58mm.	0.19mm.	3.96mm.	0.44mm.	0.66	0.07
2	11	40 w.	2.92mm.	0.38mm.	5.55mm.	0.51mm.	0.56	0.10
3	22	3.9m.	3.30mm.	0.37mm.	7.07mm.	0.56mm.	0.47	0.07
4	13	9.0m.	3.36mm.	0.33mm.	8.12mm.	0.50mm.	0.41	0.04
5	16	15.9m.	3.49mm.	0.24mm.	9.36mm.	0.74mm.	0.38	0.04
6	24	2yr.0.7m.	3.34mm.	0.32mm.	10.06mm.	0.94mm.	0.34	0.05
7	15	3yr.1 m.	3.58mm.	0.38mm.	10.82mm.	1.02mm.	0.33	0.06
8	16	4 yrs.	3.78mm.	0.45mm.	11.72mm.	1.01mm.	0.32	0.05
9	16	5 yrs.	3.62mm.	0.35mm.	11.96mm.	0.84mm.	0.30	0.03
10	14	6yr.0.5m.	3.88mm.	0.47mm.	12.79mm.	0.84mm.	0.30	0.04
11	11	7yr.6.6m.	3.92mm.	0.30mm.	13.57mm.	1.17mm.	0.29	0.04
12	19	9yr.8.5m.	4.27mm.	0.51mm.	14.78mm.	1.36mm.	0.29	0.05
13	12	11yr.6m.	4.97mm.	0.59mm.	16.60mm.	1.65mm.	0.30	0.05
14	6	13yr.7m.	5.30mm.	0.50mm.	19.18mm.	1.71mm.	0.28	0.02
15	6	Adult	5.1mm.	0.2mm.	20.00mm.	1.4mm.	0.26	0.02

Table 8b

Means and Standard Deviations for Groups 1-13

(ii) Comparison of Males and Females

Group No.	M or F	No. of Cases	Mean Age	T8-9 Mean 'Total Disc'	Standard Deviation	T8 Mean 'V.B.'	Standard Deviation	Mean Index Disc/V.B.	Standard Deviation
1	M	4	32 w.	2.63mm.	0.15mm.	3.90mm.	0.29mm.	0.67	0.12
	F	2	32 w.	2.55mm.		4.08mm.	0.80mm.	0.64	0.06
2	M	5	40 w.	3.05mm.	0.31mm.	5.56mm.	0.47mm.	0.55	0.08
	F	5	40 w.	2.90mm.	0.52mm.	5.16mm.	0.40mm.	0.57	0.13
3	M	9	4.6m.	3.34mm.	0.35mm.	7.19mm.	0.38mm.	0.48	0.06
	F	11	3.8m.	3.23mm.	0.37mm.	6.99mm.	0.67mm.	0.47	0.09
4	M	5	10 m.	3.33mm.	0.33mm.	8.34mm.	0.58mm.	0.40	0.02
	F	5	8 m.	3.35mm.	0.33mm.	7.94mm.	0.43mm.	0.42	0.05
5	M	9	16 m.	3.46mm.	0.30mm.	9.57mm.	0.46mm.	0.37	0.04
	F	5	16 m.	3.44mm.	0.16mm.	9.12mm.	1.18mm.	0.38	0.05
6	M	13	2yr.1m.	3.37mm.	0.31mm.	10.08mm.	1.00mm.	0.34	0.05
	F	10	2yr.1m.	3.26mm.	0.31mm.	10.06mm.	0.96mm.	0.33	0.04
7	M	7	3yr.1m.	3.51mm.	0.26mm.	11.11mm.	0.88mm.	0.31	0.03
	F	8	3yr.1m.	3.64mm.	0.47mm.	10.56mm.	1.12mm.	0.35	0.07
8	M	10	4 yrs.	3.77mm.	0.50mm.	11.98mm.	0.86mm.	0.32	0.05
	F	5	4 yrs.	3.89mm.	0.33mm.	11.14mm.	1.27mm.	0.35	0.04
9	M	11	5 yrs.	3.82mm.	0.40mm.	11.97mm.	0.95mm.	0.30	0.03
	F	4	5 yrs.	3.56mm.	0.29mm.	11.68mm.	0.17mm.	0.31	0.03
10	M	9	6 yrs.	3.80mm.	0.42mm.	12.67mm.	0.63mm.	0.30	0.04
	F	5	6yr.1m.	4.01mm.	0.58mm.	13.02mm.	1.17mm.	0.31	0.03

Table 8b (contd.)

Means and Standard Deviations for Groups 1-13

(ii) Comparison of Males and Females

Group No.	M or F	No. of Cases	Mean Age	T8-9 Mean 'Total Disc'	Standard Deviation	T8 Mean 'V.B.'	Standard Deviation	Mean Index Disc/V.B.	Standard Deviation
11	M	8	7yr.7m.	3.90mm.	0.31mm.	13.51mm.	0.88mm.	0.29	0.04
	F	11	7yr.4½m.	3.91mm.	0.46mm.	13.48mm.	1.36mm.	0.29	0.04
12	M	10	9yr.8m.	4.20mm.	0.40mm.	14.89mm.	1.28mm.	0.28	0.04
	F	9	9yr.9m.	4.36mm.	0.62mm.	14.66mm.	1.51mm.	0.30	0.06
13	M	2	11 yrs.	4.60mm.	0.28mm.	16.75mm.	1.06mm.	0.28	-
	F	9	11yr.8m.	5.11mm.	0.61mm.	16.47mm.	1.86mm.	0.31	0.05

Table 8b

Means and Standard Deviations for Groups 1-10

(iii) Comparison of Postmortem and X-ray Data

Group No.	P.M. and X-ray	No. of Cases	Mean Age	T8-9 Mean 'Total Disc'	Standard Deviation	T8 Mean 'V.B.'	Standard Deviation
1	P.M.	6	32 w.	2.58mm.	0.19mm.	3.96mm.	0.44mm.
	X-ray	-	-	-	-	-	-
2	P.M.	5	40 w.	3.25mm.	0.36mm.	5.24mm.	0.31mm.
	X-ray	6	40 w.	2.83mm.	0.40mm.	5.47mm.	0.53mm.
3	P.M.	3	4 m.	3.40mm.	0.44mm.	6.97mm.	0.51mm.
	X-ray	19	4 m.	3.28mm.	0.37mm.	7.08mm.	0.58mm.
4	P.M.	-	-	-	-	-	-
	X-ray	13	9 m.	3.36mm.	0.33mm.	8.12mm.	0.50mm.
5	P.M.	1	14 m.	3.40mm.	-	8.90mm.	-
	X-ray	15	16 m.	3.49mm.	0.25mm.	9.39mm.	0.74mm.
6	P.M.	-	-	-	-	-	-
	X-ray	24	2yrs.1m.	3.34mm.	0.32mm.	10.06mm.	0.94mm.
7	P.M.	3	3yrs.3m.	3.77mm.	0.72mm.	10.53mm.	1.20mm.
	X-ray	13	3yrs.1m.	3.52mm.	0.27mm.	10.95mm.	1.00mm.
8	P.M.	-	-	-	-	-	-
	X-ray	15	4 yrs.	3.81mm.	0.45mm.	11.72mm.	1.01mm.
9	P.M.	-	-	-	-	-	-
	X-ray	15	5 yrs.	3.57mm.	0.30mm.	11.90mm.	0.80mm.
10	P.M.	2	6yrs.2m.	4.45mm.	0.05mm.	12.90mm.	-
	X-ray	14	6 yrs.	3.88mm.	0.47mm.	12.79mm.	0.84mm.

Table 8b

Statistical Comparison of Thoracic Indices

(iv)

	Group No.	No. of Cases	Mean Age	Mean Index	S.D.	Student t	P
All Cases	1	6	32 w.	0.66	0.07		
	2	11	40 w.	0.56	0.10	2.10	<0.05
	3	22	3.9m.	0.47	0.07	3.25	<0.005
	4	13	9.0m.	0.41	0.04	2.77	<0.01
	5	16	15.9m.	0.38	0.04	2.50	<0.02
	6	24	2yrs.1m.	0.34	0.05	2.84	<0.01
	7	15	3yrs.1m.	0.33	0.06	0.11	<0.90
	9	16	5 years	0.30	0.03	1.96	<0.05
	15	6	Adult	0.26	0.02	3.17	<0.005
Females only - groups 6 and 8							
	6	10	2 years	0.33	0.04		
	8	5	4 years	0.35	0.04	1.08	<0.30
X-ray Cases	2	6	40 w.	0.51	0.08		
	4	13	9 m.	0.41	0.04	3.70	<0.005
	6	24	2yrs.1m.	0.34	0.05	5.23	<0.001
	9	15	5 years	0.30	0.03	2.87	<0.01
Postmortem Cases	1	6	32 w.	0.66	0.07		
	2	5	40 w.	0.62	0.09	0.14	<0.50
	3	3	5 m.	0.49	0.08	2.05	<0.10
	46,52 54,55 57	5	$3\frac{1}{2}$years	0.35	0.06	2.85	<0.05

Means of successive groups (as listed above) are compared

TABLE 8c

HEIGHTS OF VERTEBRAL BODY - C5 and of 'TOTAL DISC' - C5-6

Specimen or Name	Sex	Age		Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
GROUP 1	n = 8							
3	F	25wks.		1.6	1.7	1.95	2.05	1.22
4	F	29wks.		2.0	2.1	2.30	2.45	1.15
6	M	30wks.		2.5	2.7	2.35	2.50	0.94
7	M	30wks.		2.3	2.4	2.00	2.10	0.87
12	M	34wks.		-		2.50	2.65	
14	M	34wks.		2.6	2.8	2.50	2.65	0.96
16	F	35wks.		3.1	3.3	2.40	2.55	0.77
17	M	35wks.		2.7	2.9	2.60	2.75	0.96
GROUP 2	n = 6							
20	F	40wks.		3.5	3.7	2.40	2.55	0.69
21	F	40wks.		2.5	2.7	2.65	2.80	1.06
22	M	40wks.		3.3	3.5	2.60	2.75	0.79
23	F	40wks.		3.3	3.5	2.55	2.70	0.77
24	M	40wks.		3.5	3.7	2.90	3.05	0.83
37	M	40wks.		3.3	3.5	2.50	2.65	0.76
GROUP 3	n = 5							
Sneidon	F	3 m.	L:	3.9	3.7	3.20	3.05	0.82
Ferris	M	5 m.	L:	4.0	3.8	2.90	2.75	0.73
43	M	5 m.		3.6	3.8	3.00	3.20	0.83
Robertson	M	8 m.	AP:	4.0	3.9	2.90	2.80	0.73
X-ray 1	-	8 m.	L:	4.6	4.3	3.10	2.90	0.67
GROUP 4	n = 7							
Baird	M	9 m.	AP:	4.3	4.2	3.20	3.10	0.74
X-ray 2	-	9 m.	L:	4.5	4.2	3.15	2.95	0.70
Birbeck	F	11 m.	L:	4.2	3.9	3.00	2.80	0.71
Inch	F	14m.	L:	4.9	4.6	3.20	3.00	0.65
Laing	F	14m	AP:	4.7	4.5	3.40	3.30	0.72
X-ray 3	-	14m.	L:	4.5	4.2	3.70	3.45	0.82
46	M	14m.		4.7	5.0	3.10	3.30	0.66
GROUP 5	n = 6							
54	F	3yr.4m		5.6	5.9	4.00	4.25	0.71
55	M	3yr.9m.		6.2	6.6	4.40	4.65	0.71
X-ray 4	-	4 yrs.	L:	6.0	5.5	4.10	3.75	0.68
McFarlane	M	4 yrs.	L:	6.2	5.6	4.40	4.00	0.71
Hobkirk	F	4½yrs.	L:	7.3	6.6	4.30	3.90	0.59
X-ray 5	-	4½yrs.	L:	7.0	6.4	4.35	3.95	0.62

GROUP 6   n = 8

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
X-ray 6	-	7 yrs.	L: 8.0	7.1	5.00	4.45	0.63
Vallance	M	7 yrs.	L: 8.1	7.2	4.80	4.30	0.59
Yeoman	M	7 yrs.	L: 8.9	7.9	4.70	4.20	0.53
Hobkirk	F	8 yrs.	L: 8.3	7.4	5.00	4.45	0.60
X-ray 7	-	8 yrs.	L: 7.8	6.9	4.70	4.20	0.60
X-ray 8	-	8 yrs.	L: 8.3	7.4	5.10	4.55	0.61
Hood	M	8 yrs.	L: 6.6	5.9	4.60	4.10	0.70
Sharp	M	8 yrs.	L: 7.5	6.7	4.75	4.25	0.63

GROUP 7   n = 6

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
Knowles	F	10 yrs.	L: 8.6	7.7	4.50	4.00	0.52
Taylor	F	10 yrs.	L: 9.2	8.1	5.80	5.15	0.63
Stewart	M	11 yrs.	L: 9.3	8.2	5.90	5.20	0.63
X-ray 9	-	11 yrs.	L: 9.5	8.4	5.70	5.00	0.60
Kerr	M	12 yrs.	L: 8.0	7.0	4.70	4.10	0.59
Moncur	F	16 yrs.	L: 12.1	10.4	4.90	4.20	0.40

GROUP 8   n = 6   (Adults)

Specimen or Name	Sex	Age	Vertebral Body A	Vertebral Body B	'Total Disc' A	'Total Disc' B	Index Disc/V.B.
	F		L: 12.3	10.6	5.00	4.30	0.41
	F		L: 13.0	11.2	6.10	5.25	0.47
	F		L: 13.5	11.6	5.50	4.75	0.41
	F		L: 12.2	10.6	5.50	4.75	0.45
	M		L: 14.7	12.6	5.20	4.50	0.35
	F		L: 13.3	11.4	6.00	5.15	0.45

Table 8c

Means and Standard Deviations for Groups 1-8

(i) All cases

Group No.	No. of Cases	Mean Age	C5-6 Mean 'Total Disc'	Standard Deviation	C5 Mean 'V.B.'	Standard Deviation	Mean Index Disc/V.B.	Standard Deviation
1	8	32 w.	2.46mm.	0.26mm.	2.56mm.	0.56mm.	0.98	0.16
2	6	40 w.	2.75mm.	0.17mm.	3.43mm.	0.37mm.	0.81	0.12
3	5	5.8mm.	3.00mm.	0.28mm.	3.90mm.	0.23mm.	0.76	0.07
4	7	12 m.	3.13mm.	0.23mm.	4.37mm.	0.36mm.	0.71	0.06
5	6	4 yrs.	4.08mm.	0.32mm.	6.10mm.	0.25mm.	0.67	0.05
6	8	7yr.8m.	4.31mm.	0.16mm.	7.06mm.	0.59mm.	0.61	0.05
7	6	11yr.8m.	4.61mm.	0.56mm.	8.30mm.	1.14mm.	0.56	0.09
8	6	Adults	4.78mm.	0.37mm.	11.33mm.	0.74mm.	0.42	0.04

(There are too few cases to allow meaningful comparison of male and female data and X-ray and Postmortem data)

Table 8c

(ii) Statistical Comparison of Indices

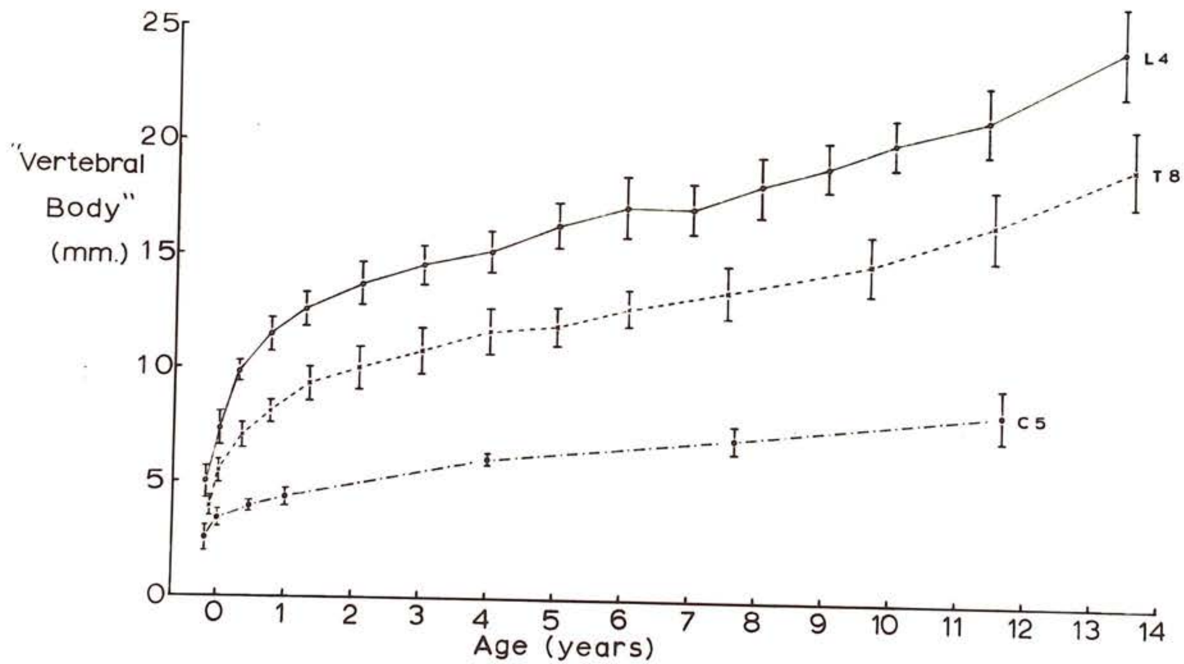
	Group No.	No. of Cases	Mean Age	Mean Index	S.D.	Student "t"	P
All cases	1	8	32 w.	0.98	0.16		
	2	6	40 w.	0.81	0.12	2.07	< 0.10
	5	6	4 yrs.	0.67	0.05	2.60	< 0.05
	6 & 7	14	9yrs5m.	0.59	0.07	2.53	< 0.025
	8	6	Adult	0.42	0.04	5.41	< 0.001

Mean indices of successive groups (as listed) are compared.

Text-fig. 19

Mean heights (with standard deviations) of vertebral bodies, L 4, T 8, and C 5

(Table 8, all cases)

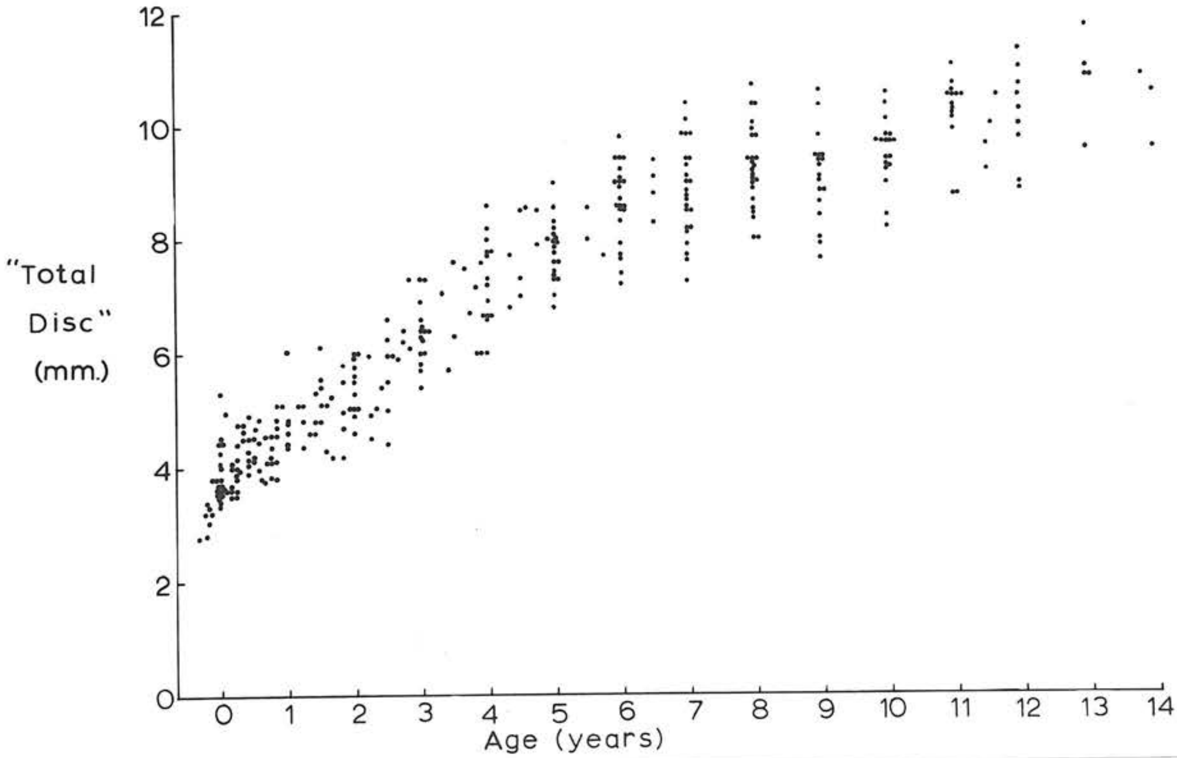

"Vertebral Body" (mm.)
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Age (years)
L4
T8
C5

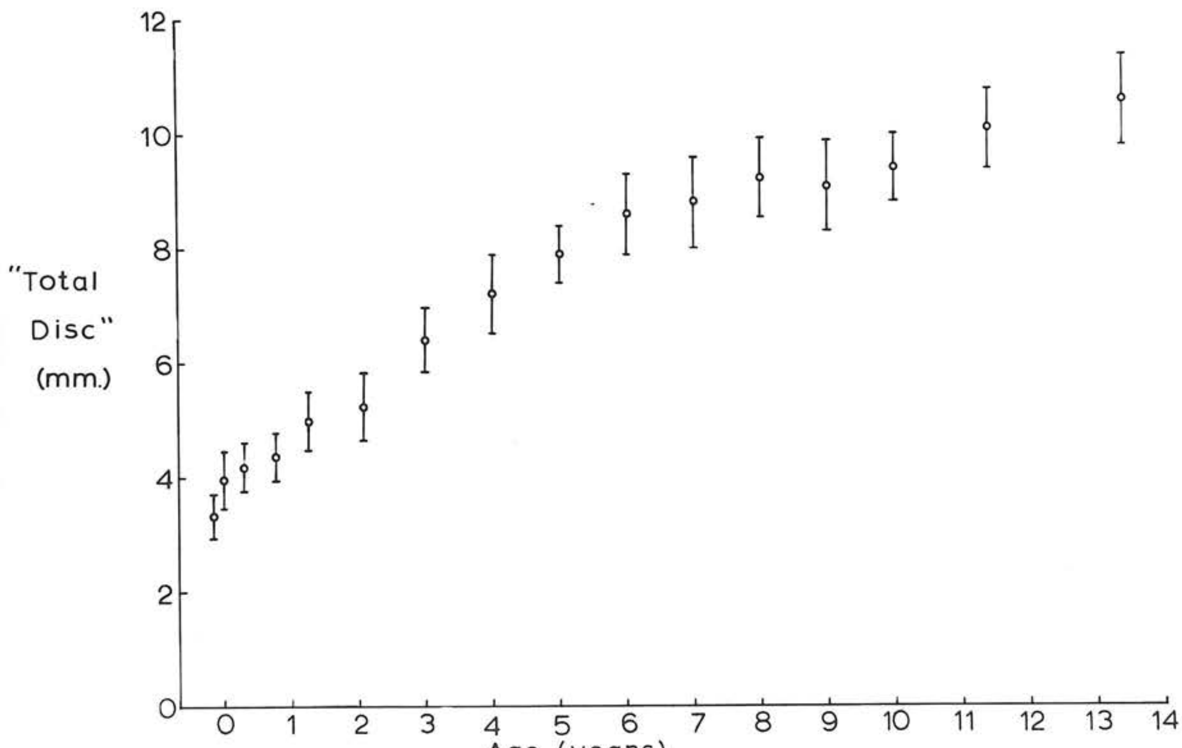
Text-fig. 20(a)

Scattergram of L 4-5 'total disc' height
(Table 8(a), all cases)

Text-fig. 20(b)

Mean heights with standard deviations
for L 4-5 'total disc'
(Table 8(a), all cases)


"Total Disc" (mm.)
Age (years)

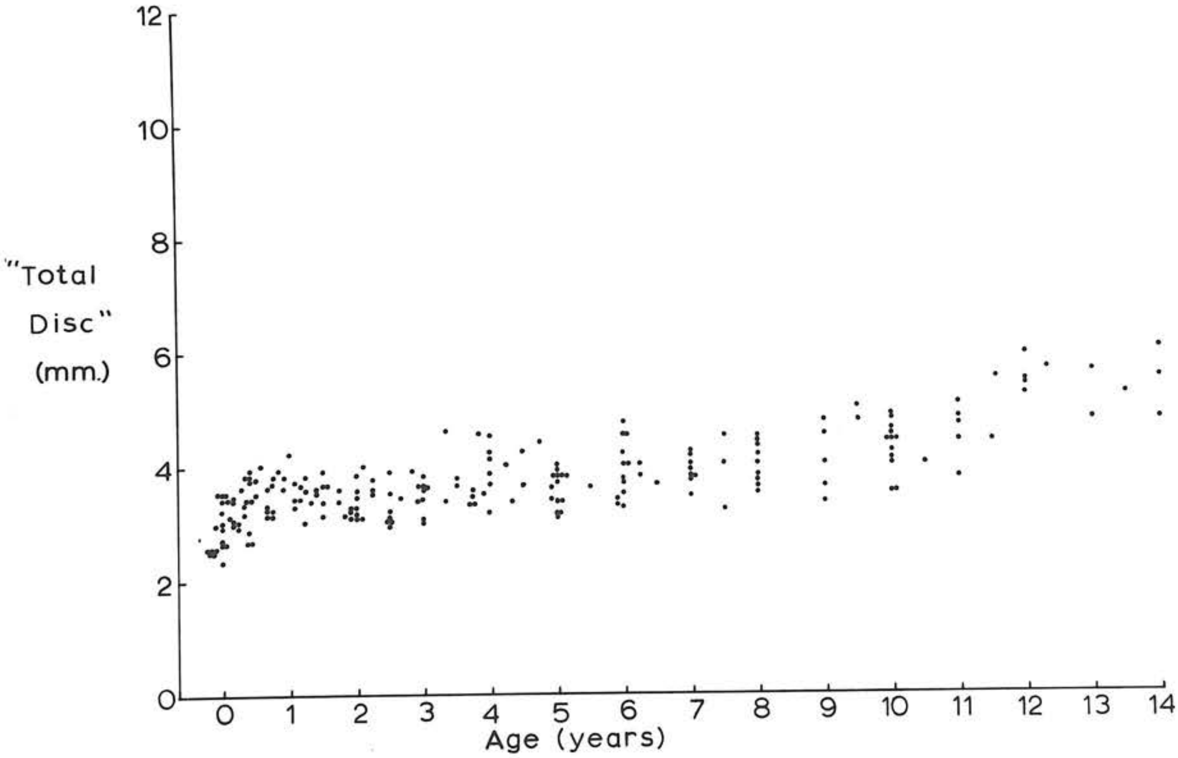

"Total Disc" (mm.)
Age (years)

Text-fig. 21(a)

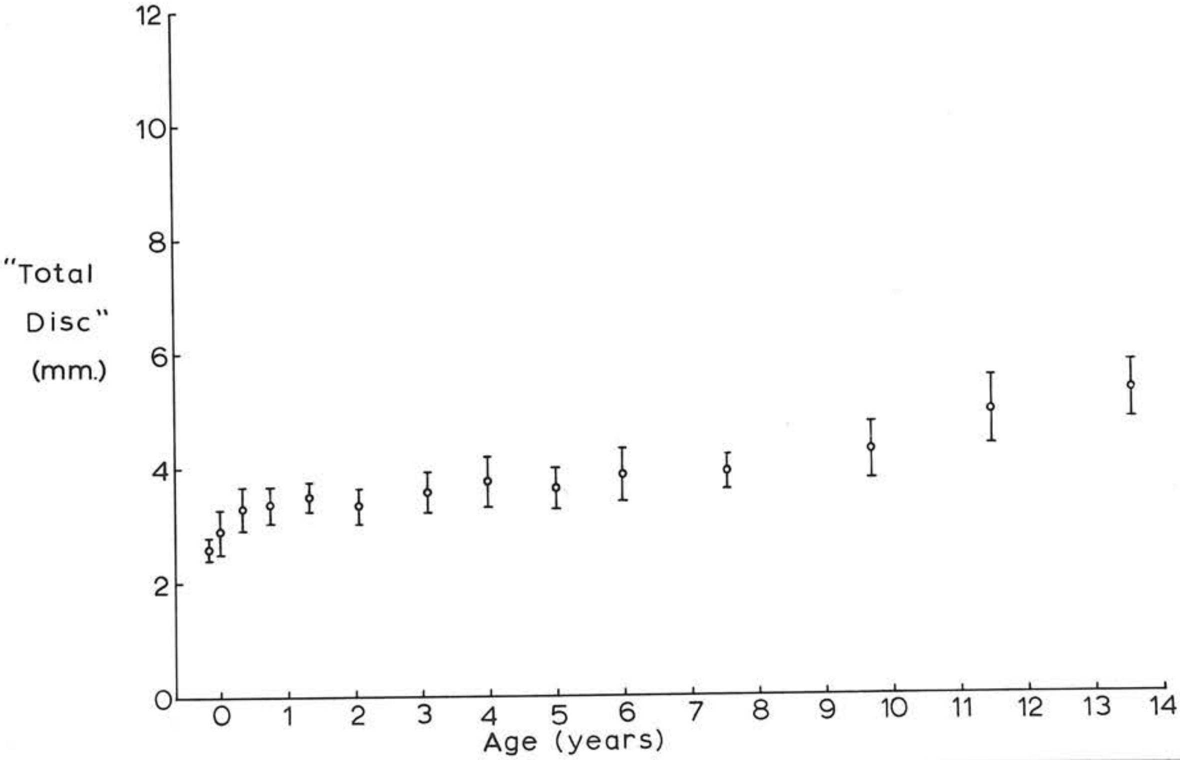
Scattergram of T 8-9 'total disc' height
(Table 8(b), all cases)

Text-fig. 21(b)

Mean heights with standard deviations
for T 8-9 'total disc'
(Table 8(b), all cases)



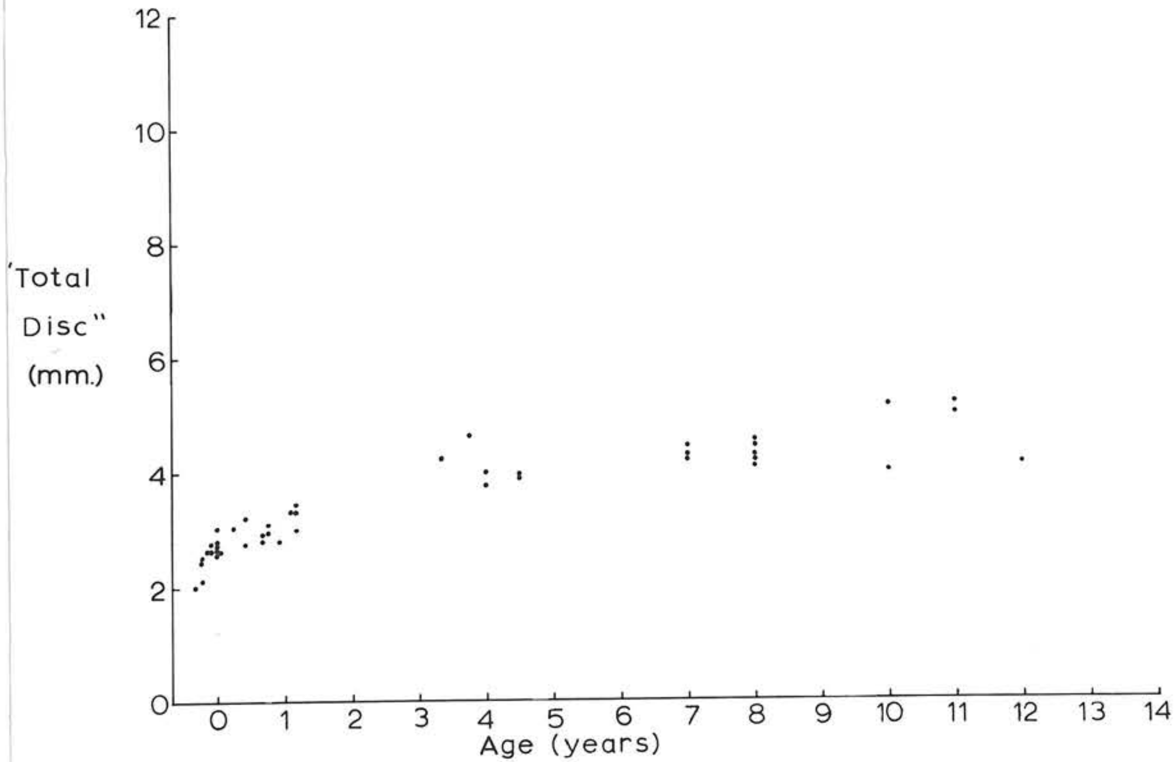
"Total Disc" (mm.)
Age (years)



"Total Disc" (mm.)
Age (years)

Text-fig. 22

Scattergram of C 5-6 'total disc' height
(Table 8(c), all cases)


'Total
Disc"
(mm.)
0
2
4
6
8
10
12
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Age (years)

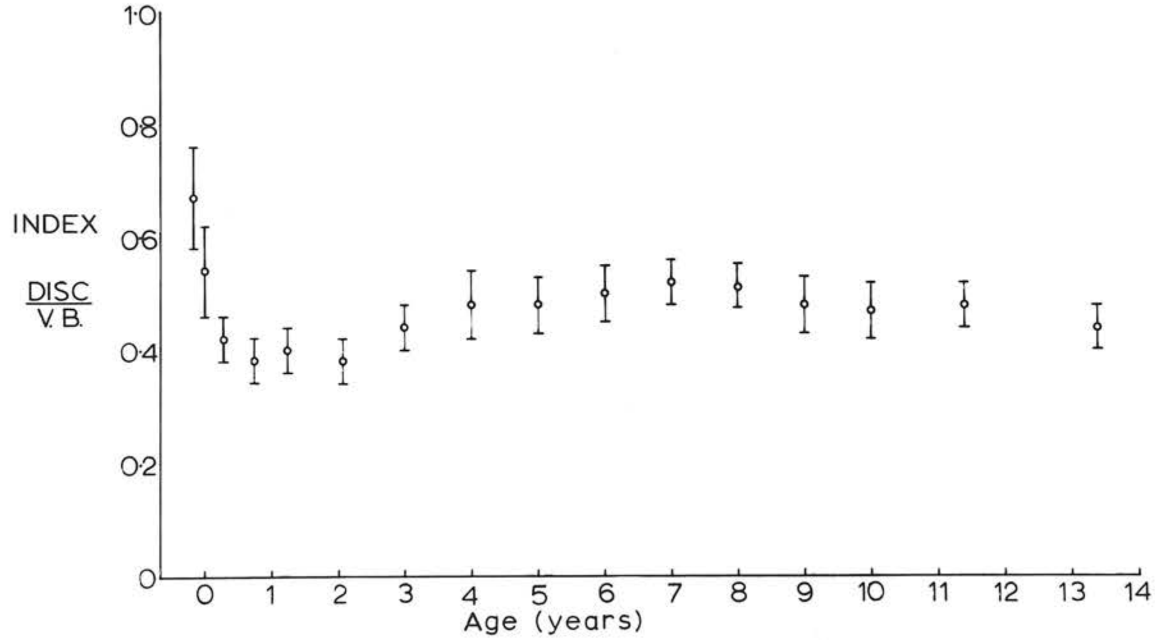
Text-fig. 23

Mean indices (with standard deviations) of $\frac{\text{'total disc' height}}{\text{vertebral body height}}$

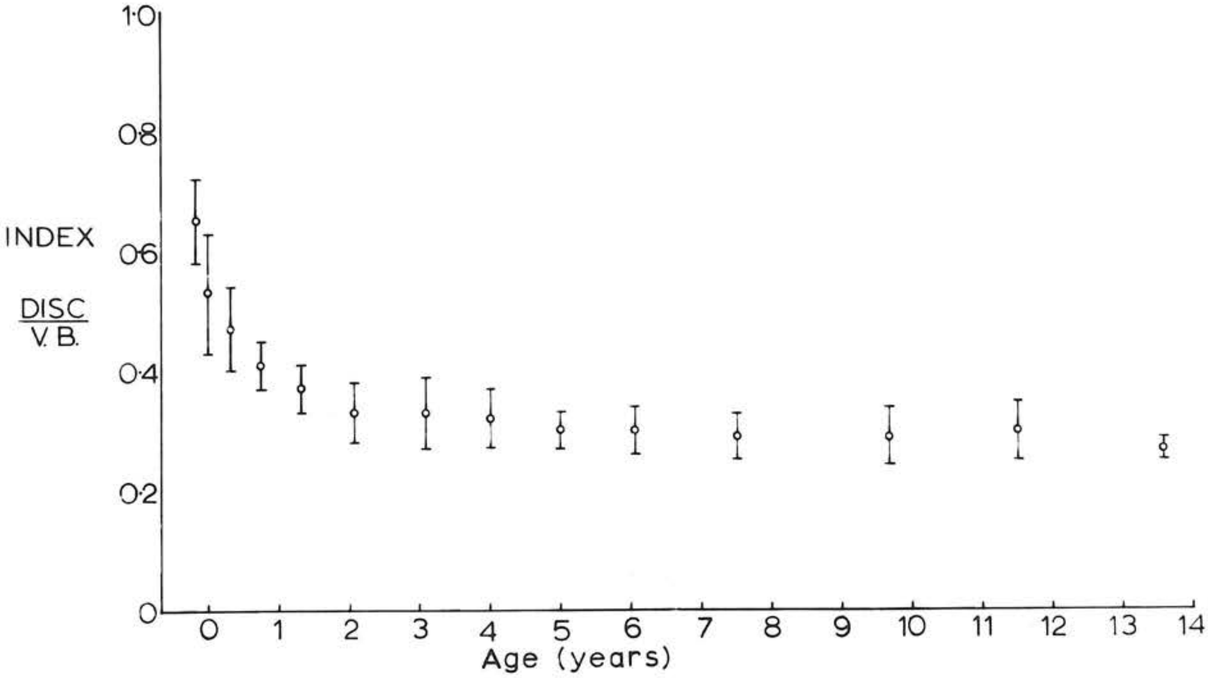
(a) $\frac{\text{L 4-5}}{\text{L 5}}$ (Table 8(a), all cases)

(b) $\frac{\text{T 8-9}}{\text{T 8}}$ (Table 8(b), all cases)

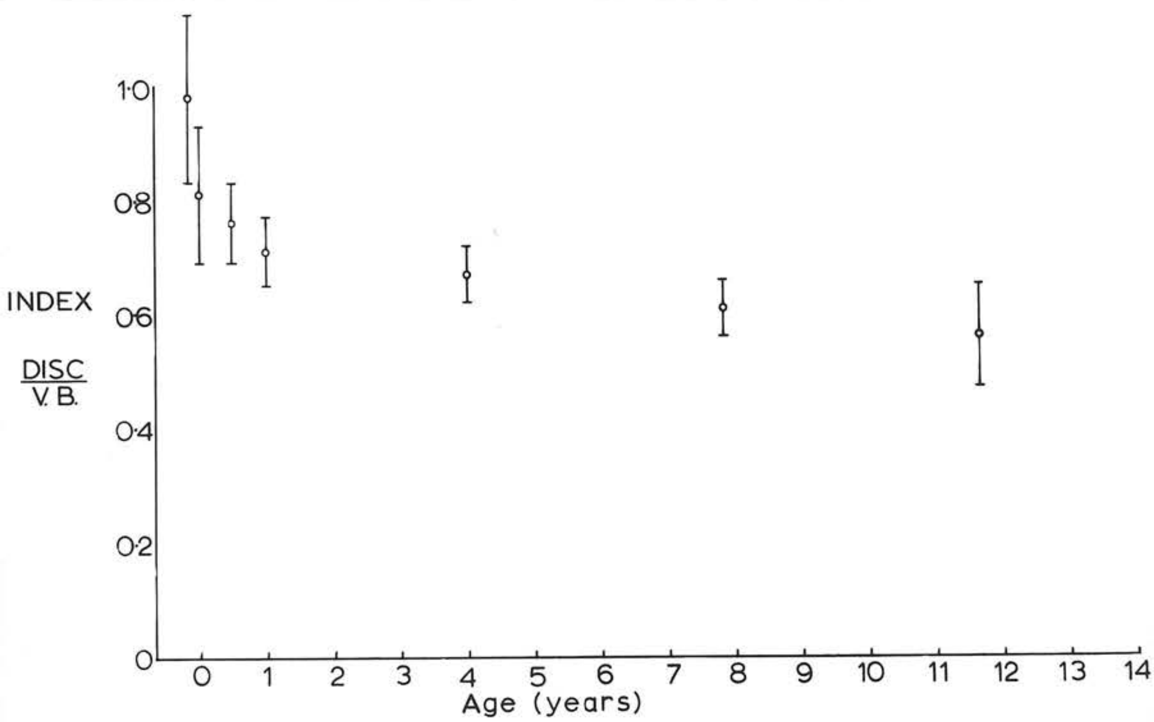
(c) $\frac{\text{C 5-6}}{\text{C 5}}$ (Table 8(c), all cases)



INDEX
DISC
V. B.
1·0
0·8
0·6
0·4
0·2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Age (years)



INDEX
DISC
V. B.
1·0
0·8
0·6
0·4
0·2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Age (years)



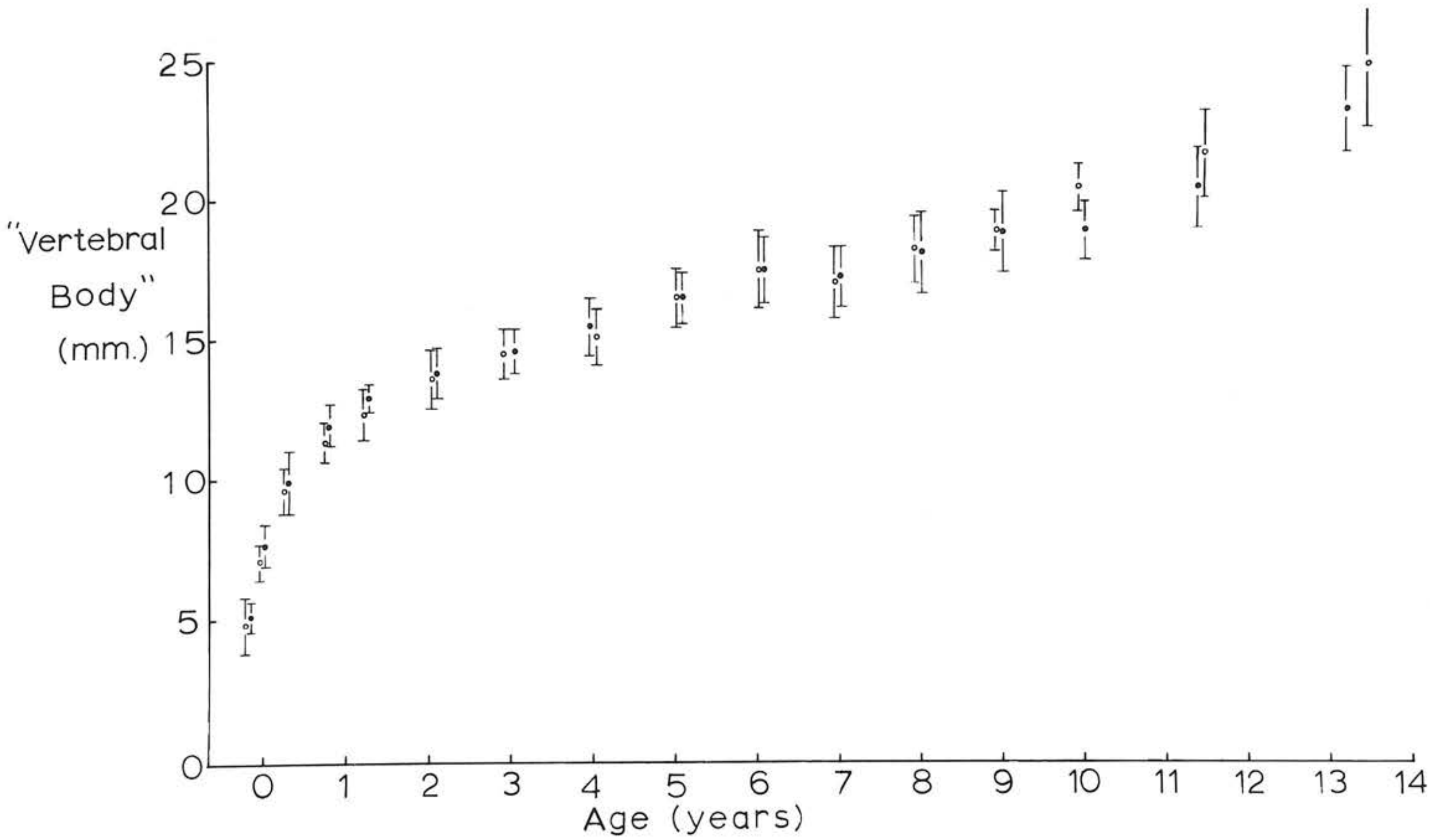
INDEX
DISC
V. B.
1·0
0·8
0·6
0·4
0·2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Age (years)

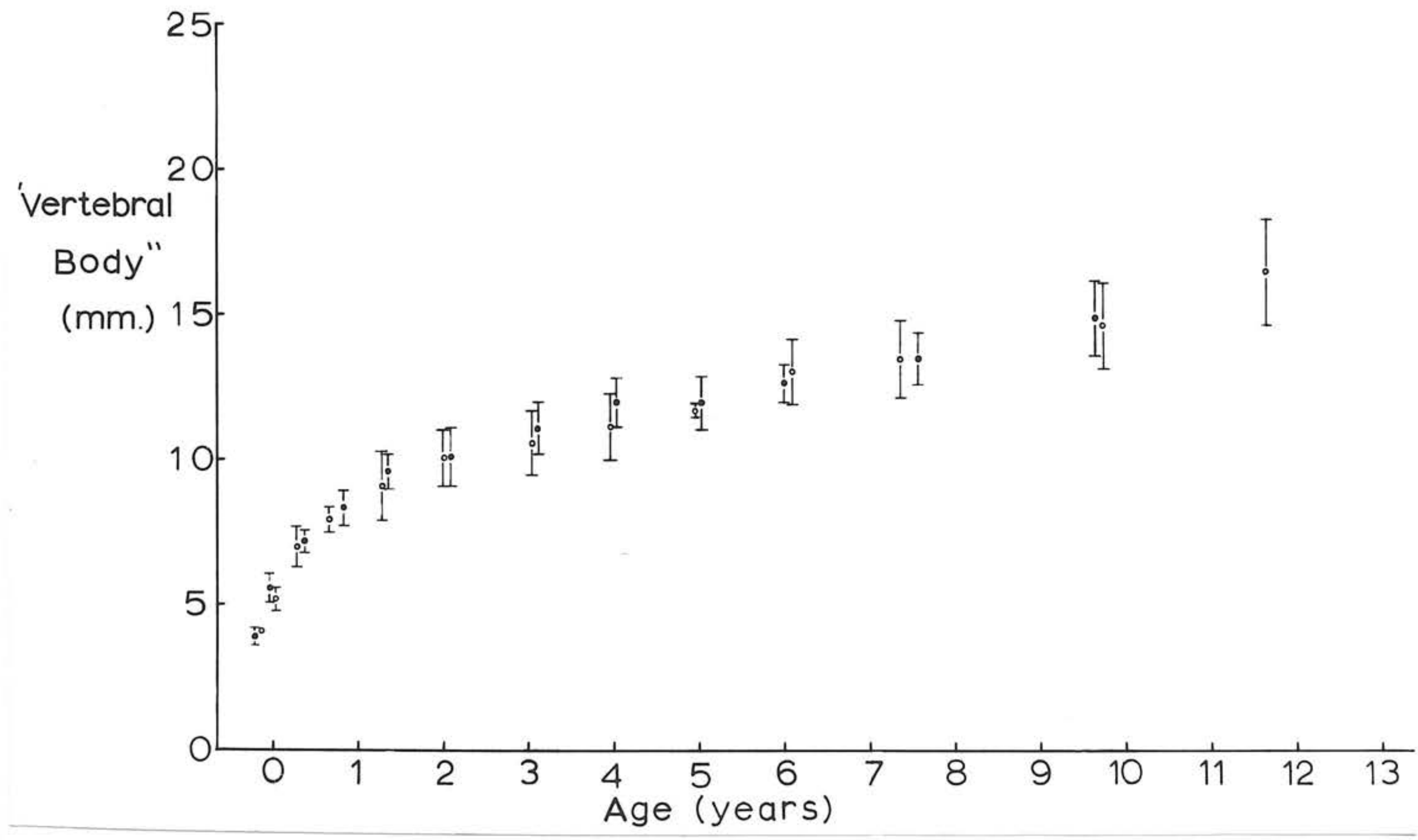
Text-fig. 24

Comparison of vertebral body heights for males -●-, and females -o-

(a) L 4. (Table 8(a))

(b) T 8. (Table 8(b))


"Vertebral Body" (mm.)
0
5
10
15
20
25
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Age (years)


'Vertebral Body" (mm.)
0
5
10
15
20
25
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Age (years)

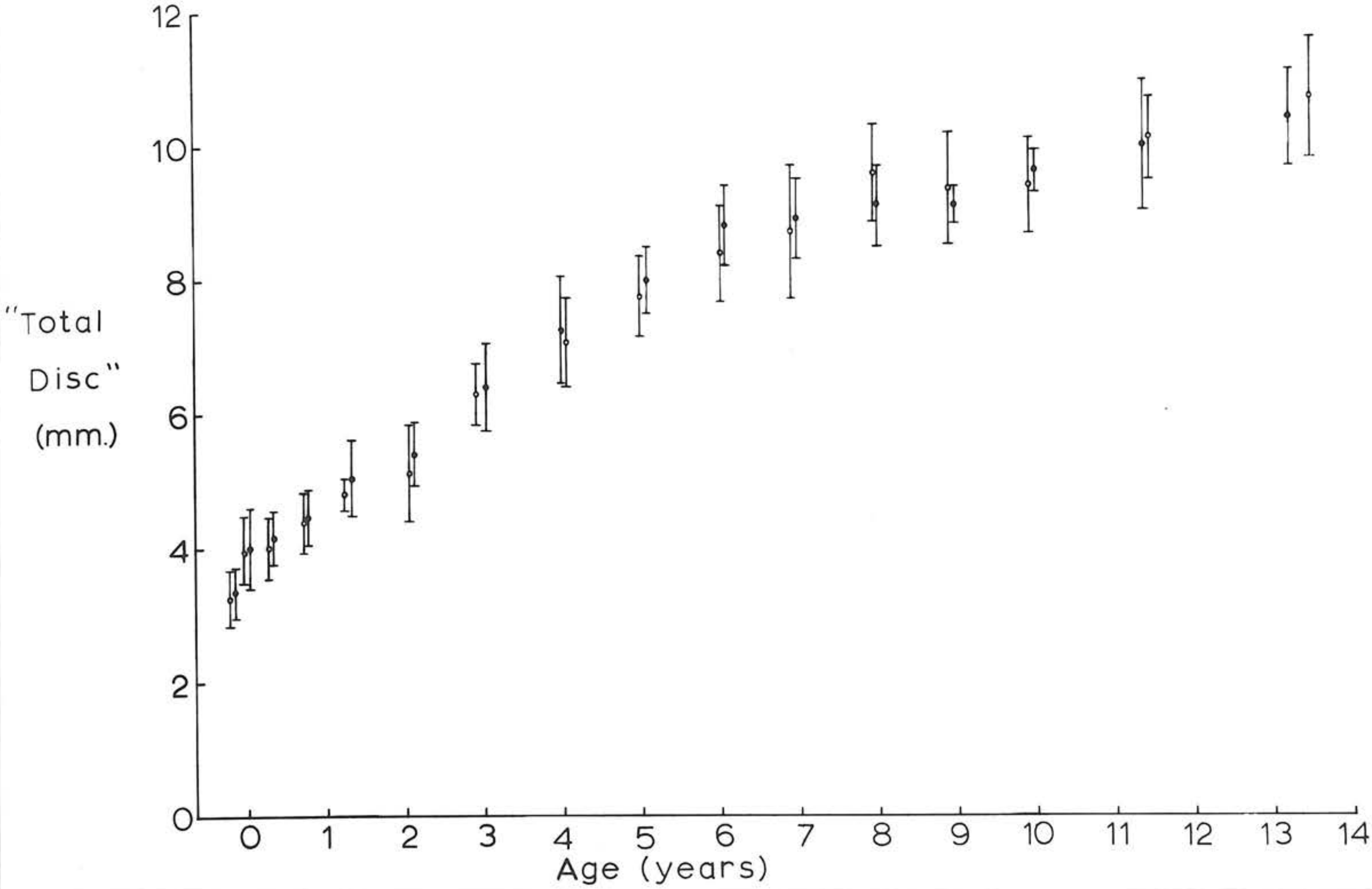
Text-fig. 25

Comparison of 'total disc' heights for

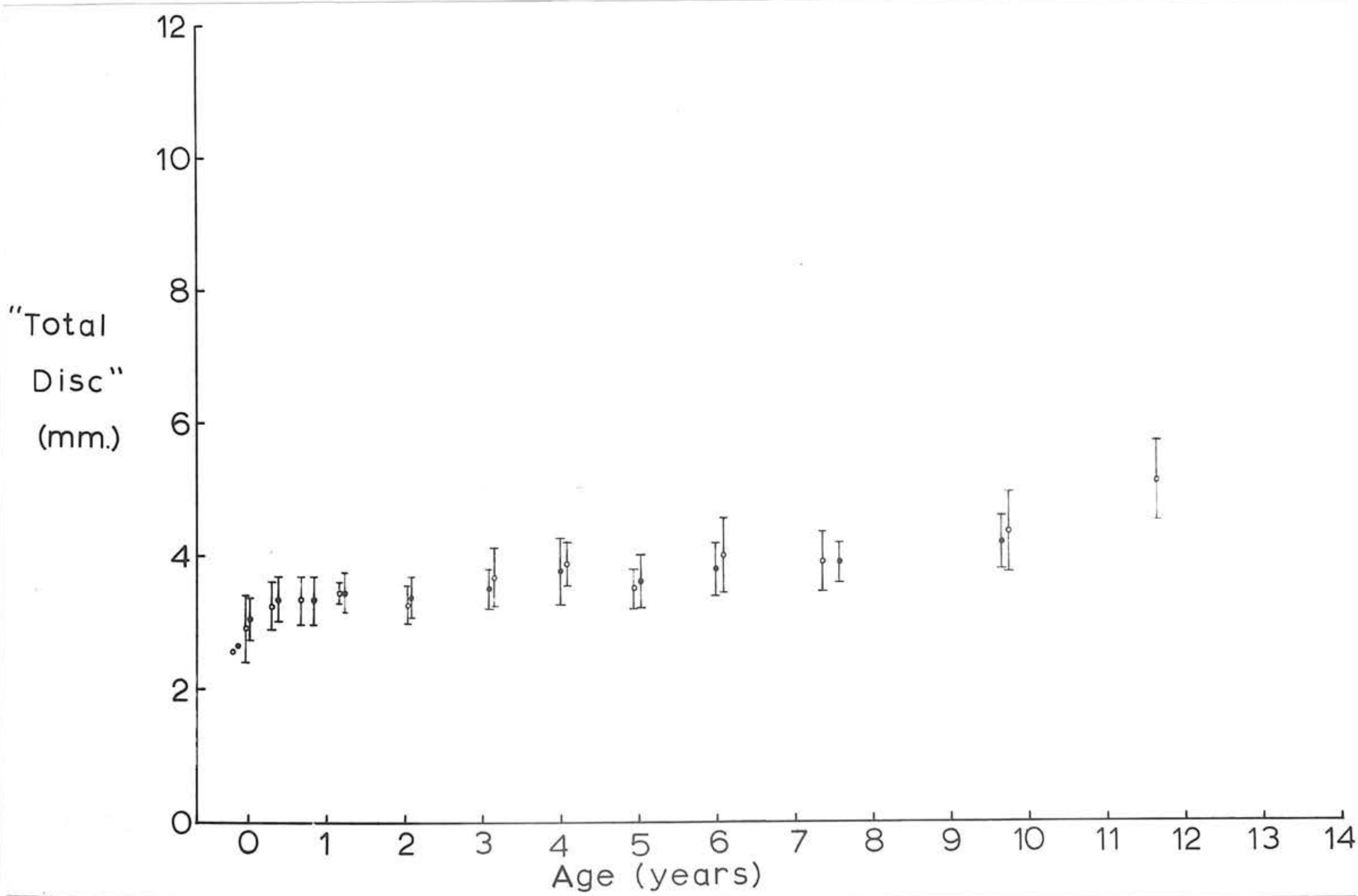
males -•-, and females -o-

(a) L 4-5 (Table 8(a))

(b) T 8-9 (Table 8(b))



"Total Disc" (mm.)
Age (years)



"Total Disc" (mm.)
Age (years)

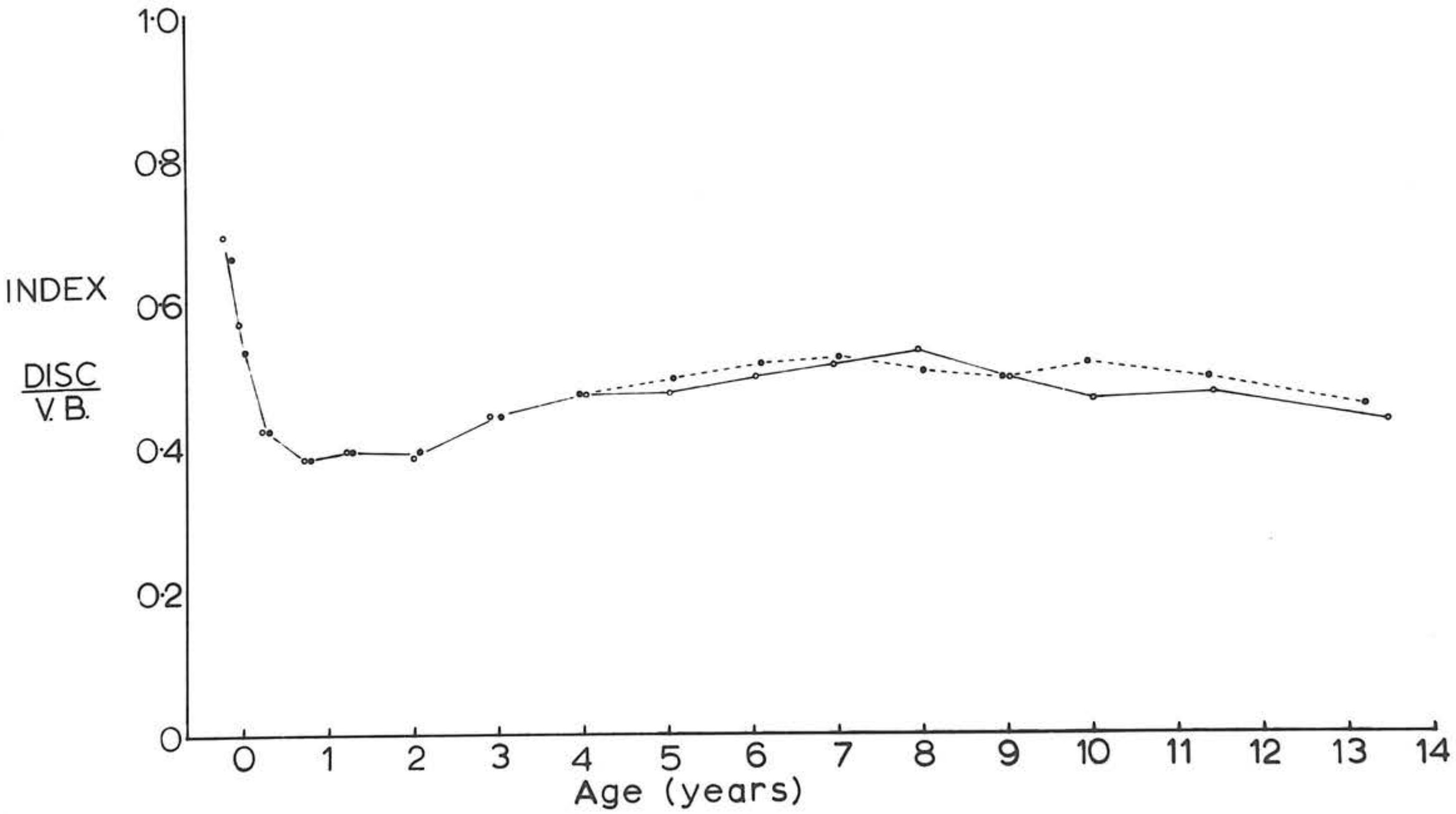
Text-fig. 26

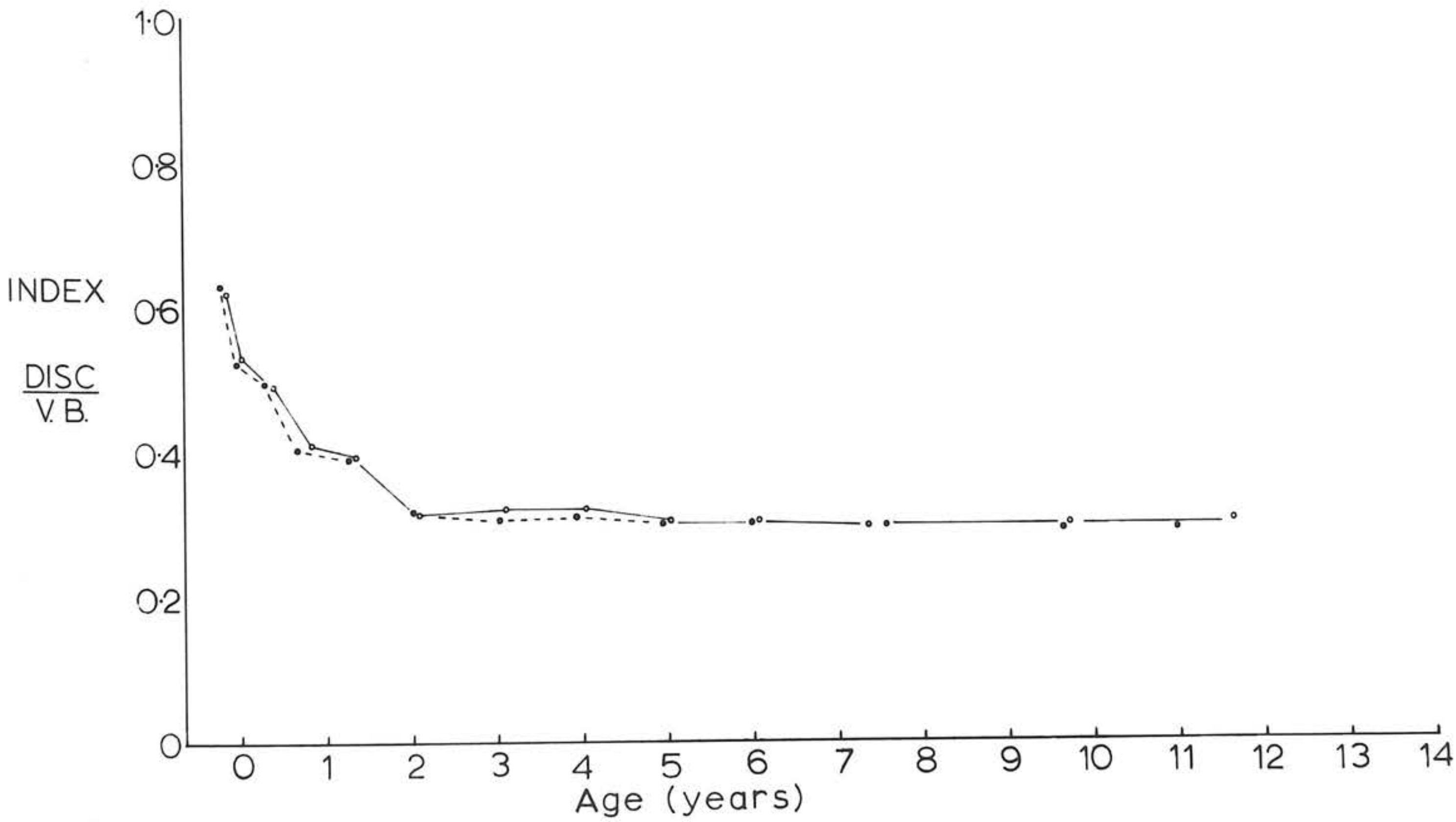
Comparison of the indices: $\frac{\text{'total disc' height}}{\text{vertebral body height}}$

for males -●-, and females -o-

(a) $\frac{L\ 4\text{-}5}{L4}$ (Table 8(a))

(b) $\frac{T\ 8\text{-}9}{T\ 8}$ (Table 8(b))


1·0
0·8
INDEX
0·6
DISC
V. B.
0·4
0·2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Age (years)

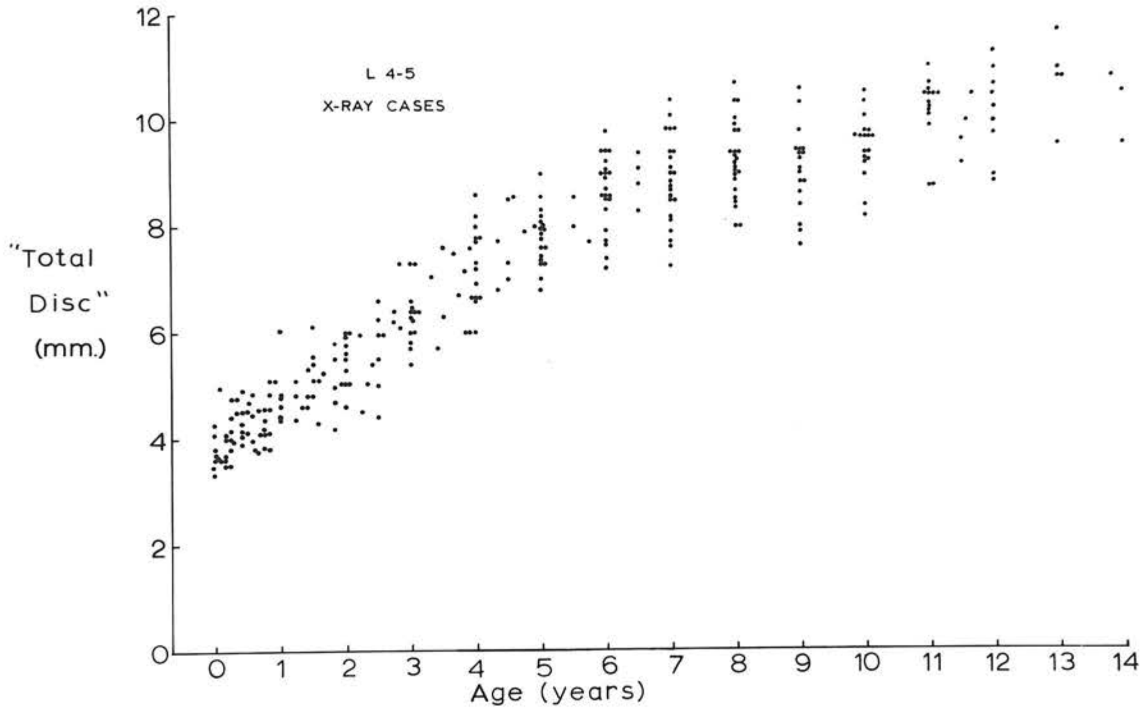

1·0
0·8
INDEX
0·6
DISC
V. B.
0·4
0·2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Age (years)

Text-fig. 27

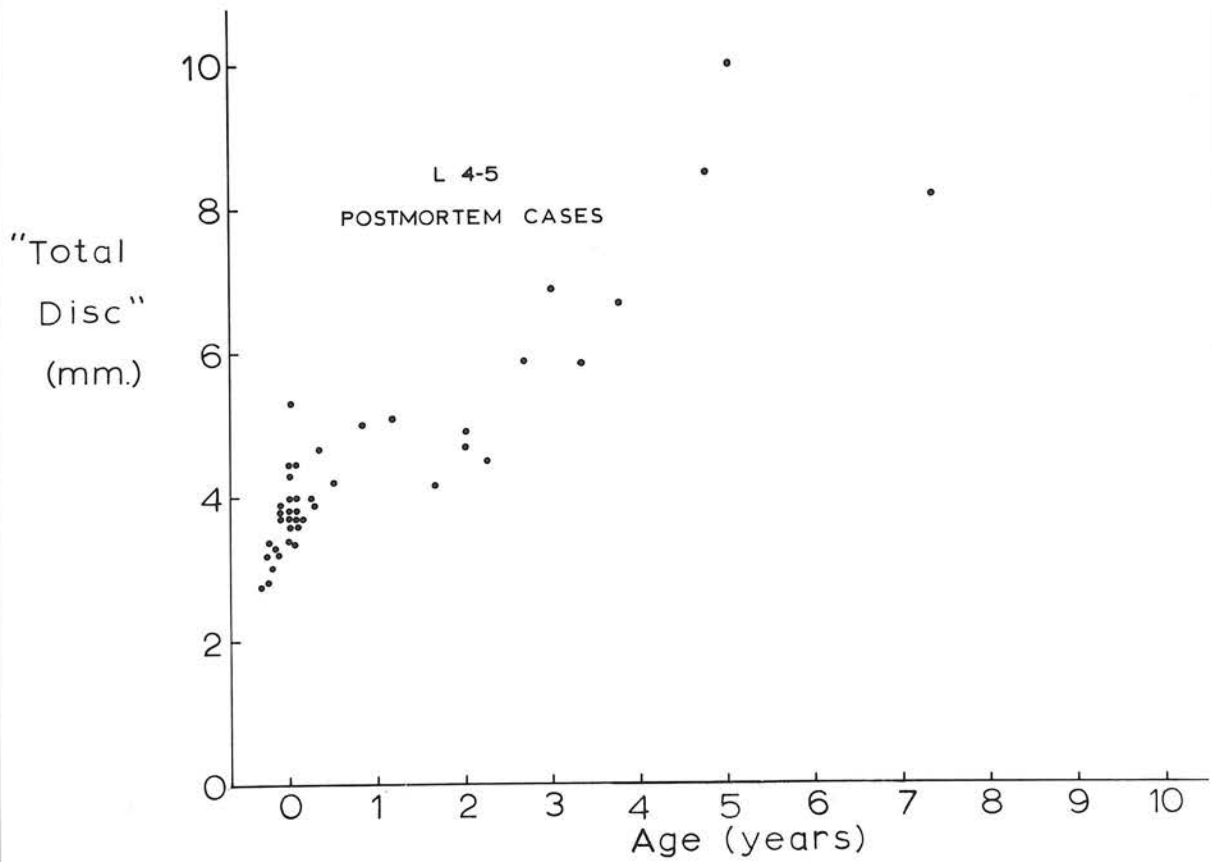
L 4-5 'total disc' heights: separation of x-ray and postmortem data

(a) Scattergram of 'total disc' heights: X-ray cases only

(b) Scattergram of 'total disc' heights: postmortem cases only



L 4-5
X-RAY CASES
"Total Disc" (mm.)
Age (years)



L 4-5
POSTMORTEM CASES
"Total Disc" (mm.)
Age (years)

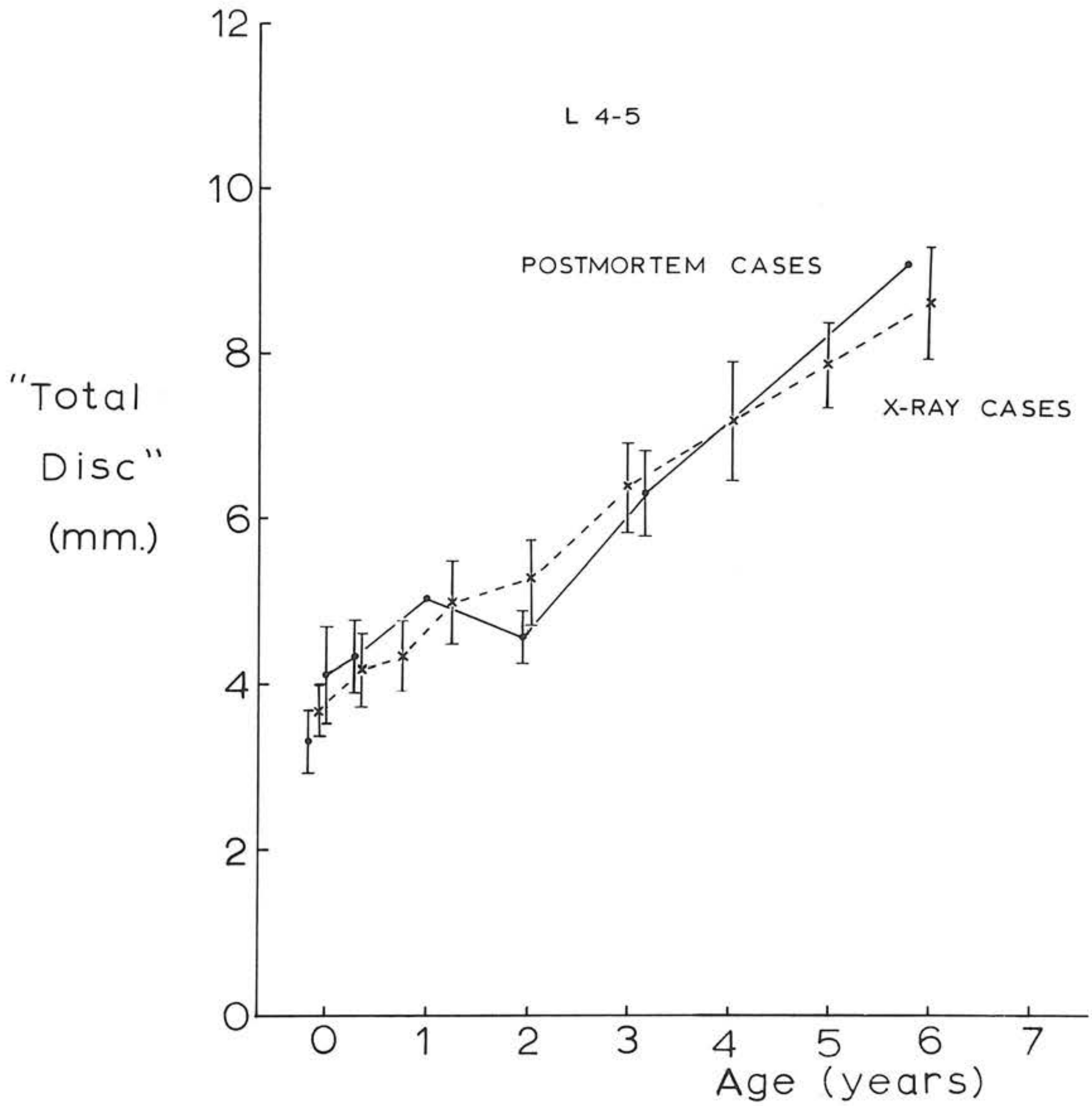
Text-fig. 28

Comparison of X-ray and postmortem means for L 4-5 'total disc' height

Postmortem means ——●——

X-ray means - - x - -

Text-fig. 28

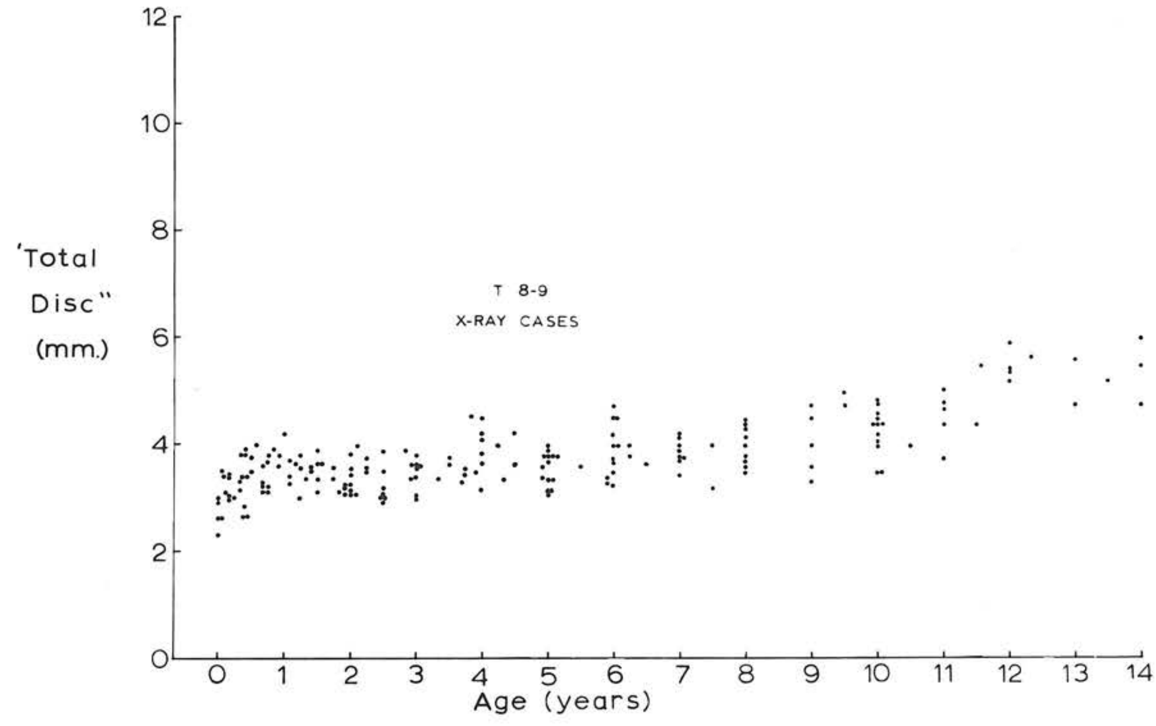

12
10
8
6
4
2
0
L 4-5
POSTMORTEM CASES
X-RAY CASES
"Total Disc" (mm.)
0
1
2
3
4
5
6
7
Age (years)

Text-fig. 29

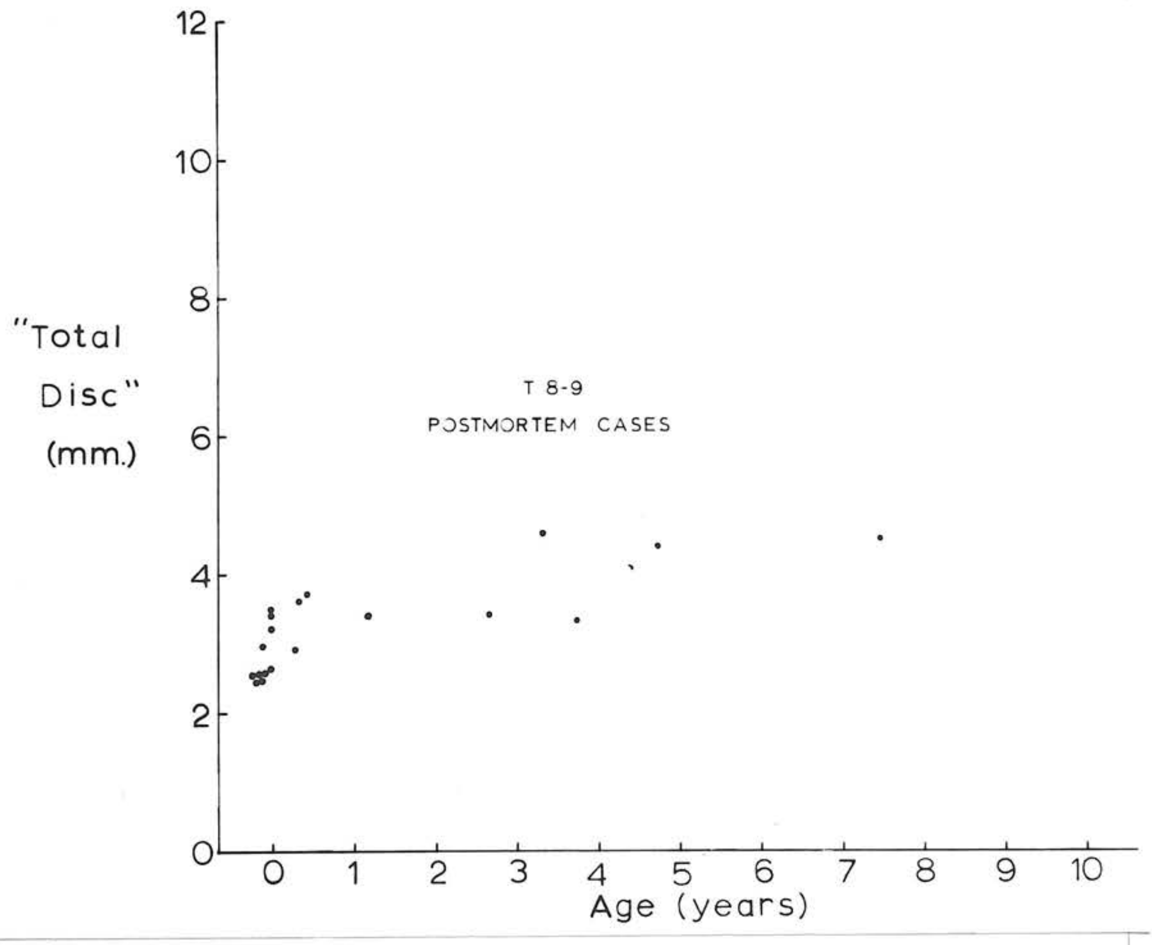
T 8-9 'total disc' heights: separation of X-ray and postmortem data

(a) Scattergram of 'total disc' heights: X-ray cases only

(b) Scattergram of 'total disc' heights: postmortem cases only



'Total
Disc"
(mm.)
T 8-9
X-RAY CASES
Age (years)



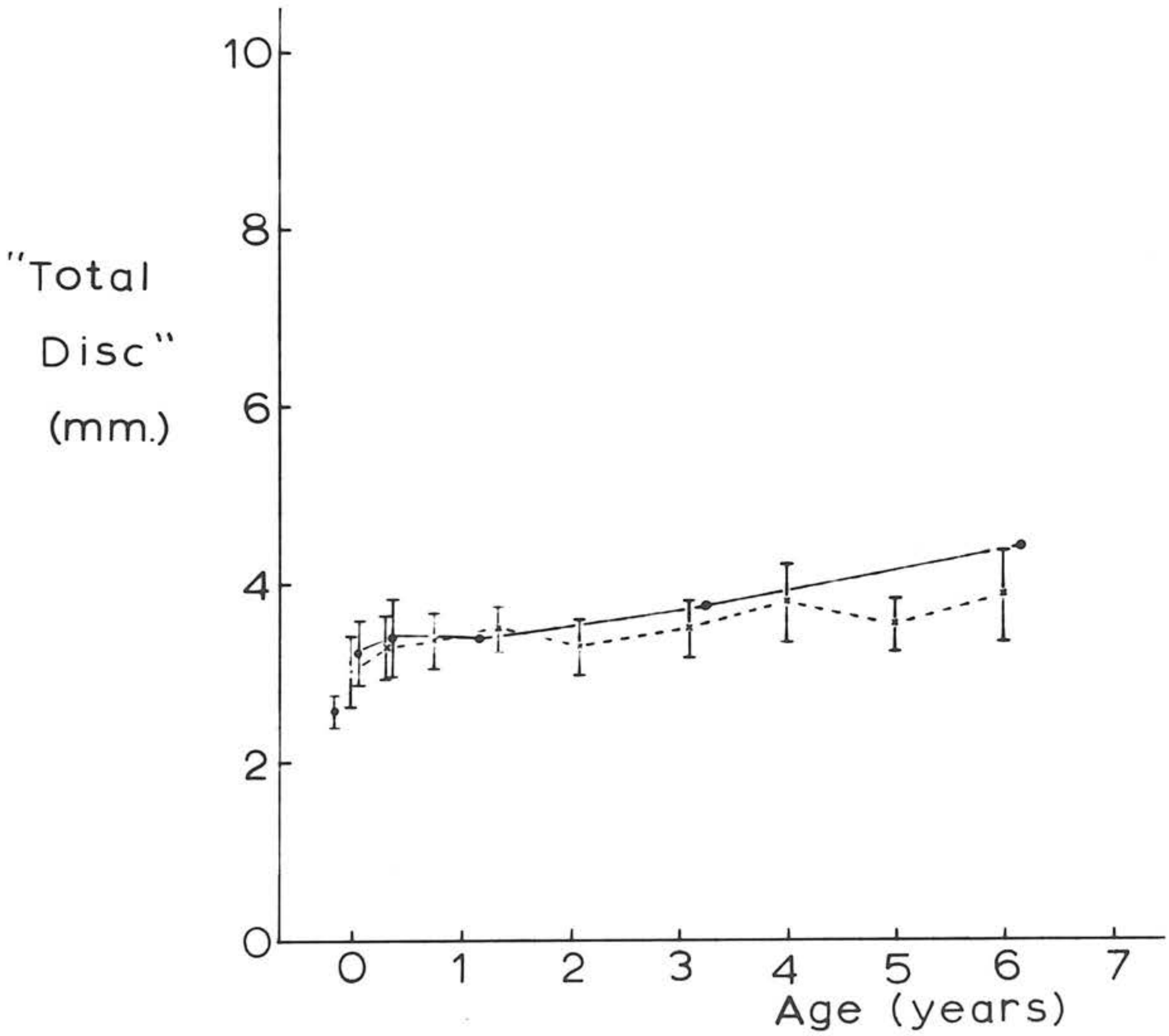
"Total
Disc"
(mm.)
T 8-9
POSTMORTEM CASES
Age (years)

Text-fig. 30

Comparison of X-ray and postmortem means
for T 8-9 'total disc' height

Postmortem means ———●———

X-ray means - - - x - - -



10
8
"Total
Disc"
(mm.)
6
4
2
0
0
1
2
3
4
5
6
7
Age (years)

Text-fig. 31

Comparison of mean indices: $\frac{L\ 4\text{-}5}{L\ 4}$

derived from X-ray and postmortem data

X-ray means - - - x - - -

Postmortem means ———o———

0·70
POSTMORTEM CASES
0·60
INDEX
DISC
V. B.
0·50
X-RAY CASES
0·40
0·35
0
0
1
2
3
4
5
6
7
8
Age (years)

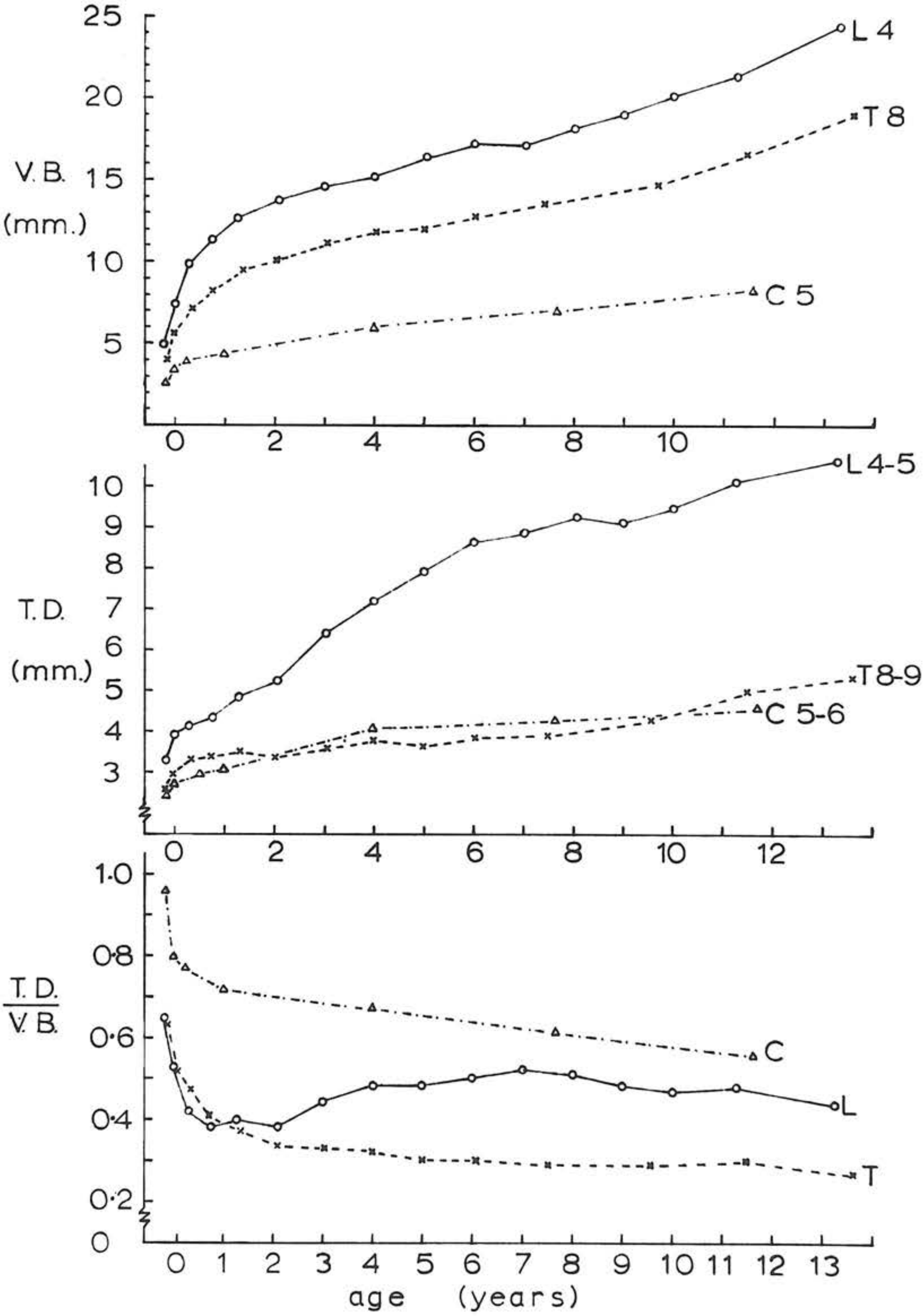
Text-fig. 32

Summary graph

(a) Mean heights of vertebral bodies L 4, T 8 and C 5 (all cases)

(b) Mean heights of 'total discs' L 4-5, T 8-9 and C 5-6 (all cases)

(c) Mean indices for $\frac{L\ 4\text{-}5}{L\ 4}$ $\frac{T\ 8\text{-}9}{T\ 8}$ and $\frac{C\ 5\text{-}6}{C\ 5}$ (all cases)



25
20
V.B.
(mm.)
15
10
5
L 4
T 8
C 5
0
2
4
6
8
10
10
9
8
T.D.
(mm.)
7
6
5
4
3
L 4-5
T8-9
C 5-6
0
2
4
6
8
10
12
1·0
0·8
T.D./V.B.
0·6
0·4
0·2
0
C
L
T
0 1 2 3 4 5 6 7 8 9 10 11 12 13
age (years)

TABLE 9(a)

LUMBAR DISCS: 'DISC PROPER': CARTILAGE PLATES: 'CARTILAGE LAYERS'

No.	Sex	Age	Disc	'Disc Proper' (mm.)	Cartilage Plates CP1	Cartilage Plates CP2	Cartilage Plates SUM	Cartilage Columns CC1	Cartilage Columns CC2	Cartilage Columns SUM	'Cartilage Layers' (CPs - CCs)
E1	-	7.5w.	L4-5	0.09	-	-	-	-	-	-	-
E3	-	8 w.	L4-5	0.13	-	-	-	-	-	-	-
E4	-	9 w.	L4-5	0.14	-	-	-	-	-	-	-
E5	-	9 w.	L4-5	0.20	-	-	-	-	-	-	-
E6	-	13.5w.	L4-5	0.40	-	-	-	-	-	-	-
1	-	18 w.	L4-5	0.50	0.70mm.	0.60mm.	1.30mm.	0.30mm.	0.30mm.	0.60mm.	0.70mm.
2	-	22 w.	L4-5	0.62	0.95mm.	0.80mm.	1.75mm.	0.30mm.	0.30mm.	0.60mm.	1.15mm.
3	F	25 w.	L4-5	0.60	1.08mm.	1.08mm.	2.16mm.	0.30mm.	0.30mm.	0.60mm.	1.56mm.
4	F	29 w.	L4-5	0.50	1.27mm.	1.22mm.	2.49mm.	0.40mm.	0.32mm.	0.72mm.	1.77mm.
5	F	30 w.	L3-4	1.02	1.33mm.	1.20mm.	2.53mm.	0.32mm.	0.35mm.	0.67mm.	1.86mm.
6	M	30 w.	L4-5	0.85	1.32mm.	1.32mm.	2.64mm.	0.32mm.	0.32mm.	0.64mm.	2.00mm.
7	M	30 w.	L4-5	0.69	1.15mm.	1.08mm.	2.23mm.	0.28mm.	0.25mm.	0.53mm.	1.70mm.
8	M	31 w.	L3-4	1.00	1.20mm.	1.16mm.	2.36mm.	0.41mm.	0.40mm.	0.81mm.	1.55mm.
9	M	31 w.	L3-4	1.39	1.36mm.	1.28mm.	2.64mm.	0.34mm.	0.32mm.	0.66mm.	1.98mm.
10	F	32 w.	L3-4	1.31	1.34mm.	1.37mm.	2.71mm.	0.39mm.	0.36mm.	0.75mm.	1.96mm.
11	F	32 w.	L3-4	0.85	1.40mm.	1.30mm.	2.70mm.	0.35mm.	0.40mm.	0.75mm.	1.95mm.
12	M	Abnormal discs.		NC very large and globular							
13	M	34 w.	L3-4	1.27	1.43mm.	1.45mm.	2.88mm.	0.30mm.	0.30mm.	0.60mm.	2.22mm.
14	M	34 w.	L4-5	0.92	1.02mm.	1.06mm.	2.08mm.	0.28mm.	0.29mm.	0.57mm.	1.51mm.
15	F	34 w.	L3-4	1.18	1.17mm.	1.17mm.	2.34mm.	0.29mm.	0.29mm.	0.58mm.	1.76mm.
16	F	35 w.	L4-5	1.15	1.35mm.	1.30mm.	2.65mm.	0.27mm.	0.27mm.	0.54mm.	2.11mm.
17	M	35 w.	L4-5	1.17	1.43mm.	1.44mm.	2.87mm.	0.42mm.	0.35mm.	0.77mm.	2.10mm.
19	M	36 w.	L4-5	1.13	1.19mm.	1.19mm.	2.38mm.	0.32mm.	0.32mm.	0.64mm.	1.74mm.

TABLE 9(a) (contd.)

No.	Sex	Age	Disc	'Disc Proper' (mm.)	Cartilage Plates CP1	Cartilage Plates CP2	Cartilage Plates SUM	Cartilage Columns CC1	Cartilage Columns CC2	Cartilage Columns SUM	'Cartilage Layers' (CPs - CCs)
21	F	38 w.	L4-5	0.95	1.53mm.	1.53mm.	3.06mm.	0.20mm.	0.22mm.	0.42mm.	2.64mm.
22	M	40 w.	L4-5	1.20	1.32mm.	1.30mm.	2.62mm.	0.21mm.	0.22mm.	0.43mm.	2.19mm.
23	F	40 w.	L4-5	1.30	1.17mm.	1.30mm.	2.47mm.	0.20mm.	0.22mm.	0.42mm.	2.05mm.
25	F	40 w.	L4-5	1.28	1.38mm.	1.32mm.	2.64mm.	0.28mm.	0.28mm.	0.56mm.	2.08mm.
26	F	40 w.	L4-5	0.83	1.88mm.	1.86mm.	3.74mm.	0.24mm.	0.24mm.	0.48mm.	3.26mm.
27	M	40 w.	L4-5	1.08	1.29mm.	1.27mm.	2.56mm.	0.23mm.	0.24mm.	0.47mm.	2.09mm.
28	F	40 w.	Severe contraction artefact evident in sections								
29	M	40 w.	L4-5	2.30	1.57mm.	1.65mm.	3.22mm.	0.30mm.	0.31mm.	0.61mm.	2.61mm.
30	M	40 w.	L3-4	1.23	1.80mm.	1.69mm.	3.49mm.	0.30mm.	0.27mm.	0.57mm.	2.92mm.
31	M	40 w.	L4-5	0.95	1.83mm.	1.92mm.	3.75mm.	0.30mm.	0.30mm.	0.60mm.	3.15mm.
32	M	40 w.	L3-4	0.98	1.35mm.	1.34mm.	2.69mm.	0.30mm.	0.27mm.	0.57mm.	2.12mm.
33	F	40 w.	L4-5	1.60	1.45mm.	1.42mm.	2.87mm.	0.30mm.	0.33mm.	0.63mm.	2.24mm.
34	M	40 w.	L3-4	1.57	1.15mm.	1.25mm.	2.40mm.	0.18mm.	0.20mm.	0.38mm.	2.02mm.
35	F	(measurements difficult in unstained sections)									
36	F	Severe contraction artefact in wax sections									
37		Abnormal discs due to NC remnants in VBs.									
38	M	2 m.	L3-4	2.00mm.	1.10mm.	1.10mm.	2.20mm.	0.25mm.	0.24mm.	0.49mm.	1.71mm.
39	M	3 m.	L4-5	1.82mm.	1.02mm.	1.02mm.	2.04mm.	0.25mm.	0.24mm.	0.49mm.	1.55mm.
40	M	$3\frac{1}{2}$m.	L4-5	1.88mm.	1.06mm.	1.06mm.	2.12mm.	0.25mm.	0.25mm.	0.50mm.	1.62mm.
41	M	4 m.	L4-5	1.50mm.	1.34mm.	1.47mm.	2.81mm.	0.23mm.	0.25mm.	0.48mm.	2.33mm.
42	M	$4\frac{1}{2}$m.	L4-5	1.75mm.	1.37mm.	1.48mm.	2.85mm.	0.24mm.	0.25mm.	0.49mm.	2.36mm.
43	M	5 m.	L4-5	2.04mm.	1.26mm.	1.19mm.	2.45mm.	0.21mm.	0.20mm.	0.41mm.	2.04mm.
44	M	6 m.	L4-5	1.70mm.	1.28mm.	1.25mm.	2.53mm.	0.25mm.	0.27mm.	0.52mm.	2.01mm.
45	F	10m.	L3-4	2.32mm.	1.09mm.	1.08mm.	2.17mm.	0.23mm.	0.22mm.	0.45mm.	1.72mm.
46	M	14m.	L4-5	2.98mm.	0.94mm.	1.08mm.	2.02mm.	0.20mm.	0.21mm.	0.41mm.	1.61mm.

TABLE 9(a) (contd.)

No.	Sex	Age	Disc	'Disc Proper' (mm.)	Cartilage Plates			Cartilage Columns			'Cartilage Layers' (CPs - CCs)
					CP1	CP2	SUM	CC1	CC2	SUM	
48	F	1yr.8m.	L4-5	2.01	0.92mm.	0.92mm.	1.84mm.	0.22mm.	0.22mm.	0.44mm.	1.40mm.
49	M	2 yrs.	L4-5	2.73	0.97mm.	0.88mm.	1.85mm.	0.22mm.	0.21mm.	0.41mm.	1.44mm.
50	F	2 yrs.	L4-5	2.23	1.11mm.	1.07mm.	2.18mm.	0.20mm.	0.18mm.	0.38mm.	1.80mm.
51	M	2yr.3m	L4-5	2.15	1.05mm.	0.97mm.	2.02mm.	0.19mm.	0.17mm.	0.36mm.	1.66mm.
52	F	2yr.8m.	L4-5	3.35	1.03mm.	1.01mm.	2.04mm.	0.20mm.	0.18mm.	0.38mm.	1.66mm.
53	F	3 yrs.	L4-5	3.55	1.30mm.	1.50mm.	2.80mm.	0.22mm.	0.22mm.	0.44mm.	2.36mm.
54	F	3yr.4m.	L4-5	3.60	1.20mm.	1.20mm.	2.40mm.	0.20mm.	0.20mm.	0.40mm.	2.00mm. *
55	M	3yr.9m.	L4-5	3.48	1.30mm.	1.27mm.	2.57mm.	0.20mm.	0.25mm.	0.45mm.	2.12mm.
56	M	Scoliosis									
57	M	4yr.9m.	L4-5	4.70	1.34mm.	1.32mm.	2.66mm.	0.20mm.	0.17mm.	0.37mm.	2.29mm.
58	M	5 yrs.	L4-5	6.70	1.45mm.	1.38mm.	2.83mm.	0.18mm.	0.18mm.	0.36mm.	2.47mm.
59	F	$7\frac{1}{2}$yrs.	L4-5	4.27	1.42mm.	1.42mm.	2.84mm.	0.22mm.	0.22mm.	0.44mm.	2.40mm.
60	M	(Excessive contraction due to splitting - no pre-fix measurements)									

(* Measurements are less accurate here since they are deduced from the thickness of horizontal sections)

Table 9a

Means and Standard Deviations (L4-5) for ten Groups

('Disc Proper', Cartilage Plates, Cartilage Columns and 'Cartilage Layers')

Group	No. in Group	Age Range	Mean Age	'Disc Proper' in mm.		Cartilage Plates (CP1 + CP2) in mm.		Cartilage Columns (CC1 + CC2) in mm.		'Cartilage Layers' (CPs - CCs) in mm.	
				Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	5(E1-6)	7.5-13.5 w.	9.4 w.	0.19	0.12	-	-	-	-	-	-
2	2(1 + 2)	18 - 22 w.	20 w.	0.56	-	1.53	-	0.60	-	0.93	-
3	7(3 - 9)	25 - 31 w.	29.4 w.	0.86	0.30	2.44	0.19	0.66	0.09	1.77	0.18
4	8(10-19)	32 - 36 w.	34 w.	1.12	0.16	2.58	0.28	0.65	0.09	1.92	0.23
5	12(21-34)	38 - 40 w.	40 w.	1.27	0.40	2.96	0.49	0.51	0.09	2.45	0.45
6	5(38-42)	2 - 4½ m.	3.5m.	1.79	0.19	2.40	0.39	0.49	0.01	1.91	0.40
7	4(43-46)	5 - 14 m.	9 m.	2.26	0.54	2.29	0.24	0.45	0.05	1.85	0.21
8	5(48-52)	1yr.8m - 2yrs.8m.	2yrs.1m.	2.50	0.53	1.99	0.14	0.39	0.03	1.59	0.17
9	3(53-55)	3yrs. - 3yrs.9m.	3yrs.4m.	3.54	0.06	2.59	0.20	0.43	-	2.16	0.18
10	3(57-59)	4yrs.9m - 7yrs.6m.	5yrs.9m.	5.22	1.30	2.78	0.10	0.39	-	2.39	0.09

Text-fig. 33

Mean heights (thicknesses) of cartilage plates, 'cartilage layers' and cartilage columns, for the postmortem L 4-5 discs

C.P. = sum of two cartilage plate heights

c.c. = sum of two cartilage column heights

C.P.-c.c. = sum of two 'cartilage layer' heights

(see Table 9(a) and Text-fig. 8(b))

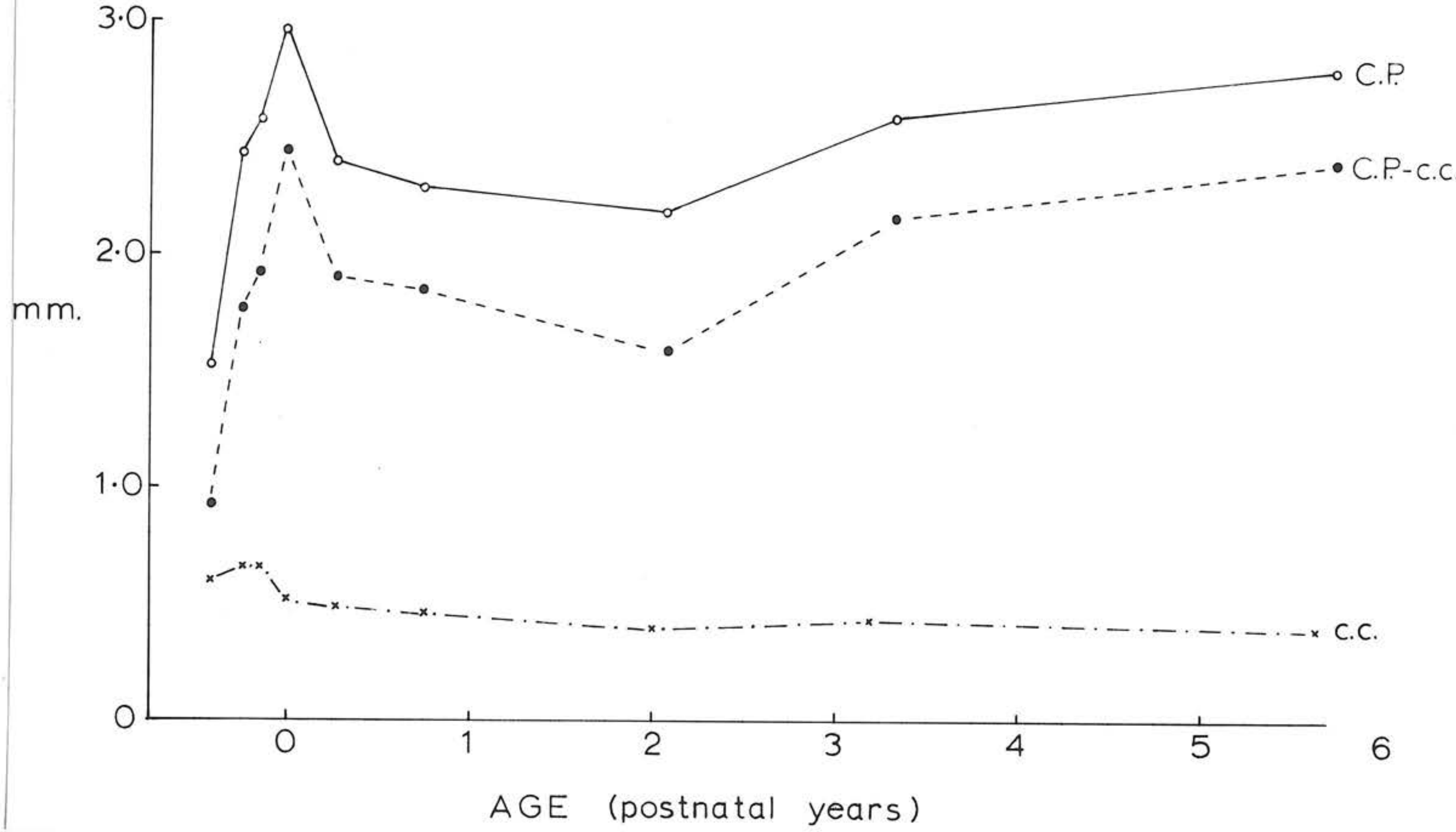

3·0
2·0
1·0
0
mm.
C.P.
C.P.-c.c.
c.c.
0
1
2
3
4
5
6
AGE (postnatal years)

TABLE 9(b)

THORACIC DISCS: 'DISC PROPER': CARTILAGE PLATES: 'CARTILAGE LAYERS'

No.	Sex	Age	Disc	'Disc Proper'	Cartilage Plates			Cartilage Columns			'Cartilag Layers' (CPs - CCs)
					CP1	CP2	SUM	CC1	CC2	SUM	
E1	-	7.5 w.	T7-8	0.06mm.	-	-	-	-	-	-	-
E3	-	8.0 w.	T8-9	0.09mm.	-	-	-	-	-	-	-
E4	-	9.0 w.	T8-9	0.12mm.	-	-	-	-	-	-	-
E5	-	9.0 w.	T8-9	0.13mm.	-	-	-	-	-	-	-
E6	-	13.5w.	T8-9	0.33mm.	-	-	-	-	-	-	-
1	-	18 w.	T7-8	0.32mm.	0.55mm.	0.55mm.	1.10mm.	0.30mm.	0.30mm.	0.60mm.	0.50mm.
2	-	22 w.	T7-8	0.60mm.	0.70mm.	0.65mm.	1.35mm.	0.35mm.	0.35mm.	0.70mm.	0.65mm.
4	F	29 w.	T8-9	0.40mm.	1.08mm.	1.04mm.	2.12mm.	0.30mm.	0.28mm.	0.58mm.	1.54mm.
6	M	30 w.	T9-10	0.57mm.	1.08mm.	1.06mm.	2.14mm.	0.40mm.	0.43mm.	0.83mm.	1.31mm.
7	M	30 w.	T8-9	0.52mm.	0.98mm.	1.00mm.	1.98mm.	0.25mm.	0.28mm.	0.53mm.	1.45mm.
14	M	34 w.	T8-9	0.67mm.	0.92mm.	0.92mm.	1.84mm.	0.32mm.	0.36mm.	0.68mm.	1.16mm.
16	F	35 w.	T8-9	0.57mm.	0.98mm.	0.96mm.	1.94mm.	0.28mm.	0.26mm.	0.54mm.	1.40mm.
17	M	35 w.	T8-9	0.93mm.	1.07mm.	0.93mm.	2.00mm.	0.20mm.	0.20mm.	0.40mm.	1.60mm.
20	F	40 w.	T8-9	0.87mm.	1.12mm.	1.12mm.	2.24mm.	0.25mm.	0.18mm.	0.43mm.	1.81mm.
21	F	38/40w	T8-9	0.70mm.	1.00mm.	0.96mm.	1.96mm.	0.24mm.	0.20mm.	0.44mm.	1.52mm.
22	M	40 w.	T8-9	1.15mm.	1.13mm.	1.10mm.	2.23mm.	0.20mm.	0.20mm.	0.40mm.	1.83mm.
23	F	40 w.	T8-9	0.88mm.	1.27mm.	1.15mm.	2.42mm.	0.30mm.	0.25mm.	0.55mm.	1.87mm.
24	M	40 w.	T8-9	1.02mm.	1.06mm.	1.05mm.	2.11mm.	0.22mm.	0.23mm.	0.45mm.	1.66mm.
40	M	$3\frac{1}{2}$ m.	T8-9	0.98mm.	0.90mm.	0.85mm.	1.75mm.	0.23mm.	0.22mm.	0.45mm.	1.30mm.
42	M	$4\frac{1}{2}$ m.	T8-9	1.10mm.	1.24mm.	1.19mm.	2.43mm.	0.25mm.	0.25mm.	0.50mm.	1.93mm.
43	M	5 m.	T8-9	1.53mm.	0.98mm.	1.01mm.	1.99mm.	0.16mm.	0.16mm.	0.32mm.	1.67mm.
46	M	14 m.	T8-9	1.46mm.	1.05mm.	0.95mm.	2.00mm.	0.20mm.	0.20mm.	0.40mm.	1.60mm.

TABLE 9(b) (contd)

No.	Sex	Age	Disc	'Disc Proper'	Cartilage Plates			Cartilage Columns			'Cartilage Layers' (CPs - CCs)
					CP1	CP2	SUM	CC1	CC2	SUM	
52	F	2yr 8m.	T8-9	1.59mm.	0.79mm.	0.76mm.	1.55mm.	0.20mm.	0.22mm.	0.42mm.	1.13mm.
54	F	3yr 4m.	T8-9	3.10mm.	0.86mm.	0.80mm.	1.66mm.	0.25mm.	0.25mm.	0.50mm.	1.16mm.
55	M	3yr 9m.	T8-9	1.22mm.	0.84mm.	0.92mm.	1.76mm.	0.20mm.	0.20mm.	0.40mm.	1.36mm.
57	M	4yr 9m.	T8-9	2.13mm.	0.75mm.	0.82mm.	1.57mm.	0.15mm.	0.20mm.	0.35mm.	1.22mm.
59	F	7yr 6m.	T8-9	2.60mm.	0.89mm.	0.85mm.	1.74mm.	0.11mm.	0.16mm.	0.27mm.	1.47mm.

Table 9b

Means and Standard Deviations (T8-9) for six Groups

('Disc Proper', Cartilage Plates, Cartilage Columns and 'Cartilage Layers')

Group	No. in Group	Age Range	Mean Age	'Disc Proper' in mm.		Cartilage Plates (CP1 + CP2) in mm.		Cartilage Columns (CC1 + CC2) in mm.		'Cartilage Layers' (CPs - CCs) in mm.	
				Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	5	7.5-13.5 w.	9.4 w.	0.15	0.11	-	-	-	-	-	-
2	2	18 - 22 w.	20 w.	0.46	-	1.23	-	0.65	-	0.57	-
3	6	29 - 35 w.	32 w.	0.61	0.18	2.00	0.11	0.59	0.14	1.41	0.16
4	5	38 - 40 w.	40 w.	0.92	0.17	2.19	0.17	0.45	0.06	1.74	0.15
5	4	$3\frac{1}{2}$ - 14 m.	6.8 m.	1.27	0.27	2.04	0.28	0.42	0.08	1.63	0.26
6	5	2yrs. 8m. - 7yrs. 6m.	4yrs.5m.	2.13	0.76	1.66	0.10	0.39	0.09	1.27	0.14

Text-fig. 34

Mean heights (thicknesses) of cartilage plates, 'cartilage layers' and cartilage columns, for the postmortem T8-9 discs

C.P.	Sum of two cartilage plate heights
c.c.	Sum of two cartilage column heights
C.P.-c.c.	Sum of two 'cartilage layer' heights

(see Table 9(b) and Text-fig. 8(b))

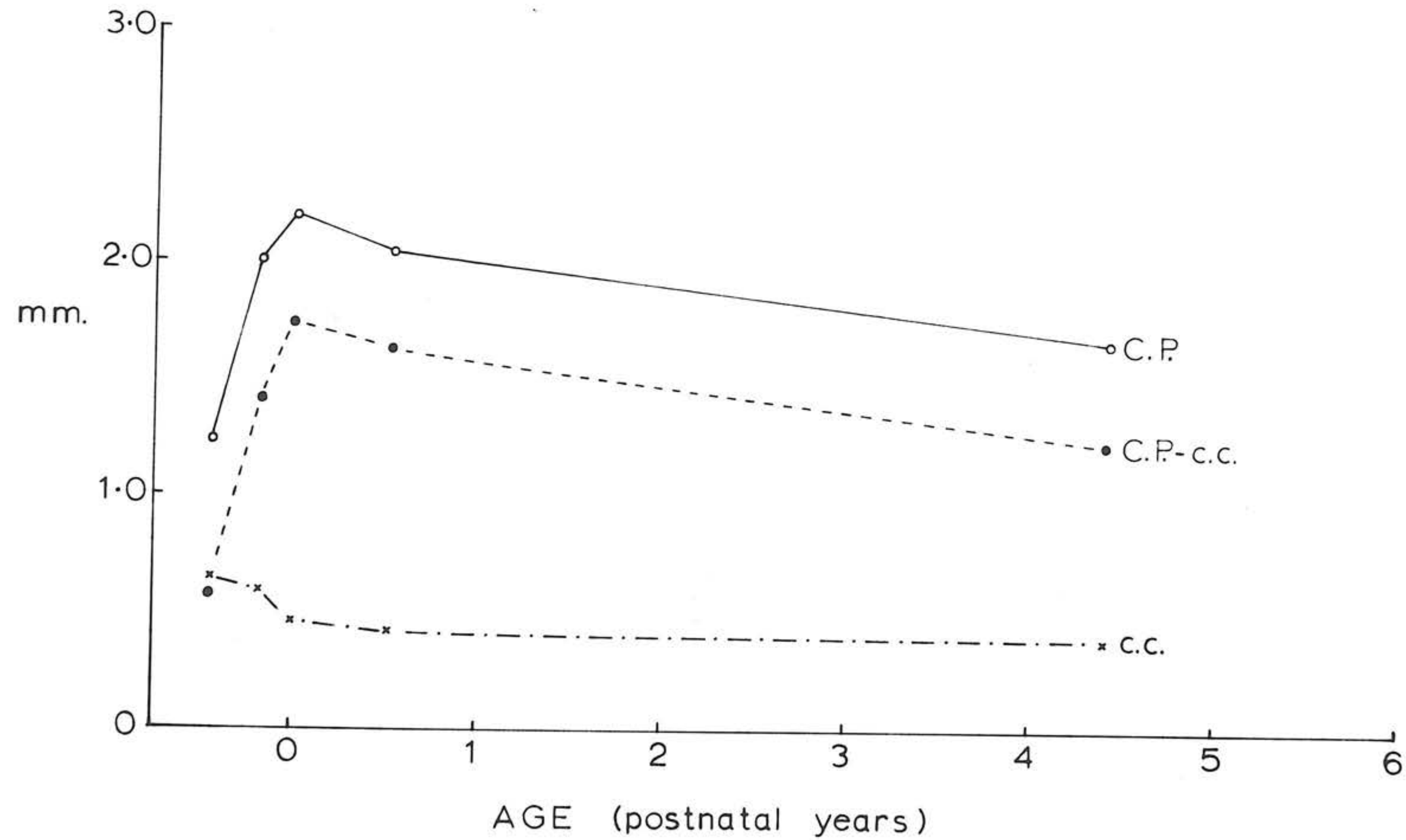

3·0
2·0
1·0
0
mm.
C.P.
C.P.-c.c.
c.c.
0
1
2
3
4
5
6
AGE (postnatal years)

TABLE 9(c)

CERVICAL DISCS: 'DISC PROPER': CARTILAGE PLATES: 'CARTILAGE LAYERS'

No.	Sex	Age	Disc	'Disc Proper'	Cartilage Plates			Cartilage Columns			'Cartilage Layers' (CPs - CCs)
					CP1	CP2	SUM	CC1	CC2	SUM	
E1	-	7.5 w.	C4-5	0.06mm.	-	-	-	-	-	-	-
E2	-	7.5 w.	C4-5	0.07mm.	-	-	-	-	-	-	-
E3	-	8 w.	C5-6	0.12mm.	-	-	-	-	-	-	-
E4	-	9 w.	C5-6	0.13mm.	-	-	-	-	-	-	-
E5	-	9 w.	C5-6	0.15mm.	-	-	-	-	-	-	-
E6	-	13.5 w.	C5-6	0.37mm.	-	-	-	-	-	-	-
1	-	18 w.	C5-6	0.50mm.	0.60mm.	0.60mm.	1.20mm.	0.30mm.	0.30mm.	0.60mm.	0.60mm.
2	-	22 w.	C5-6	0.60mm.	0.65mm.	0.60mm.	1.25mm.	0.30mm.	0.30mm.	0.60mm.	0.65mm.
3	F	25 w.	C5-6	0.42mm.	0.80mm.	0.80mm.	1.60mm.	0.25mm.	0.25mm.	0.50mm.	1.10mm.
4	F	29 w.	C5-6	0.44mm.	1.00mm.	0.97mm.	1.97mm.	0.20mm.	0.20mm.	0.40mm.	1.57mm.
6	M	30 w.	C5-6	0.50mm.	0.96mm.	1.00mm.	1.96mm.	0.30mm.	0.28mm.	0.58mm.	1.38mm.
7	M	30 w.	C5-6	0.52mm.	0.80mm.	0.75mm.	1.55mm.	0.20mm.	0.20mm.	0.40mm.	1.15mm.
14	M	34 w.	C5-6	0.70mm.	0.96mm.	0.97mm.	1.93mm.	0.24mm.	0.24mm.	0.48mm.	1.45mm.
16	F	35 w.	C6-7	0.65mm.	1.03mm.	0.99mm.	2.02mm.	0.25mm.	0.25mm.	0.50mm.	1.52mm.
17	M	35 w.	C5-6	0.87mm.	0.96mm.	0.96mm.	1.92mm.	0.25mm.	0.28mm.	0.53mm.	1.39mm.
21	F	38/40w.	C5-6	0.83mm.	1.02mm.	0.98mm.	2.00mm.	0.22mm.	0.22mm.	0.44mm.	1.56mm.
22	M	40 w.	C5-6	0.93mm.	0.95mm.	1.00mm.	1.95mm.	0.20mm.	0.20mm.	0.40mm.	1.55mm.
23	F	40 w.	C5-6	0.87mm.	0.91mm.	0.90mm.	1.81mm.	0.18mm.	0.18mm.	0.36mm.	1.45mm.
24	M	40 w.	C5-6	1.00mm.	1.01mm.	0.92mm.	1.93mm.	0.28mm.	0.25mm.	0.53mm.	1.40mm.
25	F	40 w.	C5-6	0.90mm.	1.00mm.	0.93mm.	1.93mm.	0.28mm.	0.23mm.	0.51mm.	1.42mm.
37	M	1 m.	C5-6	0.87mm.	0.91mm.	0.85mm.	1.76mm.	0.18mm.	0.20mm.	0.38mm.	1.38mm.
43		5 m.	C5-6	1.15mm.	0.97mm.	0.99mm.	1.96mm.	0.17mm.	0.16mm.	0.33mm.	1.63mm.
46		14 m.	C5-6	1.55mm.	0.87mm.	0.87mm.	1.74mm.	0.13mm.	0.16mm.	0.29mm.	1.45mm.
54		3yr 4m.	C6-7	2.15mm.	0.92mm.	0.90mm.	1.82mm.	0.19mm.	0.17mm.	0.36mm.	1.46mm.
55		3yr 9m.	C6-7	2.50mm.	6.93mm.	0.83mm.	1.76mm.	0.20mm.	0.20mm.	0.40mm.	1.36mm.

Table 9c

Means and Standard Deviations (Cervical) for five Groups

('Disc Proper', Cartilage Plates, Cartilage Columns and 'Cartilage Layers')

Group	No. in Group	Age Range	Mean Age	'Disc Proper' in mm.		Cartilage Plates (CP1 + CP2) in mm.		Cartilage Columns (CC1 + CC2) in mm.		'Cartilage Layers' (CPs - CCs) in mm.	
				Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	6	7.5-13.5 w.	9.1 w.	0.15	0.11	-	-	-	-	-	-
2	3	18 - 25 w.	22 w.	0.51	0.09	1.35	0.22	0.57	0.06	0.78	0.28
3	6	29 - 35 w.	32 w.	0.61	0.16	1.89	0.17	0.48	0.07	1.41	0.15
4	6	38w. - 1 m.	40 w.	0.90	0.06	1.90	0.09	0.44	0.07	1.46	0.08
5	4	5 months - 3yrs. 9m.	2yrs2m.	1.84	0.60	1.82	0.10	0.35	0.05	1.48	0.11

Text-fig. 35

Mean heights (thicknesses) of cartilage plates, 'cartilage layers' and cartilage columns for the postmortem C 5-6 discs

C.P. = Sum of two cartilage plate heights

c.c. = Sum of two cartilage dolumn heights

C.P.-c.c. = Sum of two 'cartilage layer' heights

(see Table 9(c) and Text-fig. 8(b))

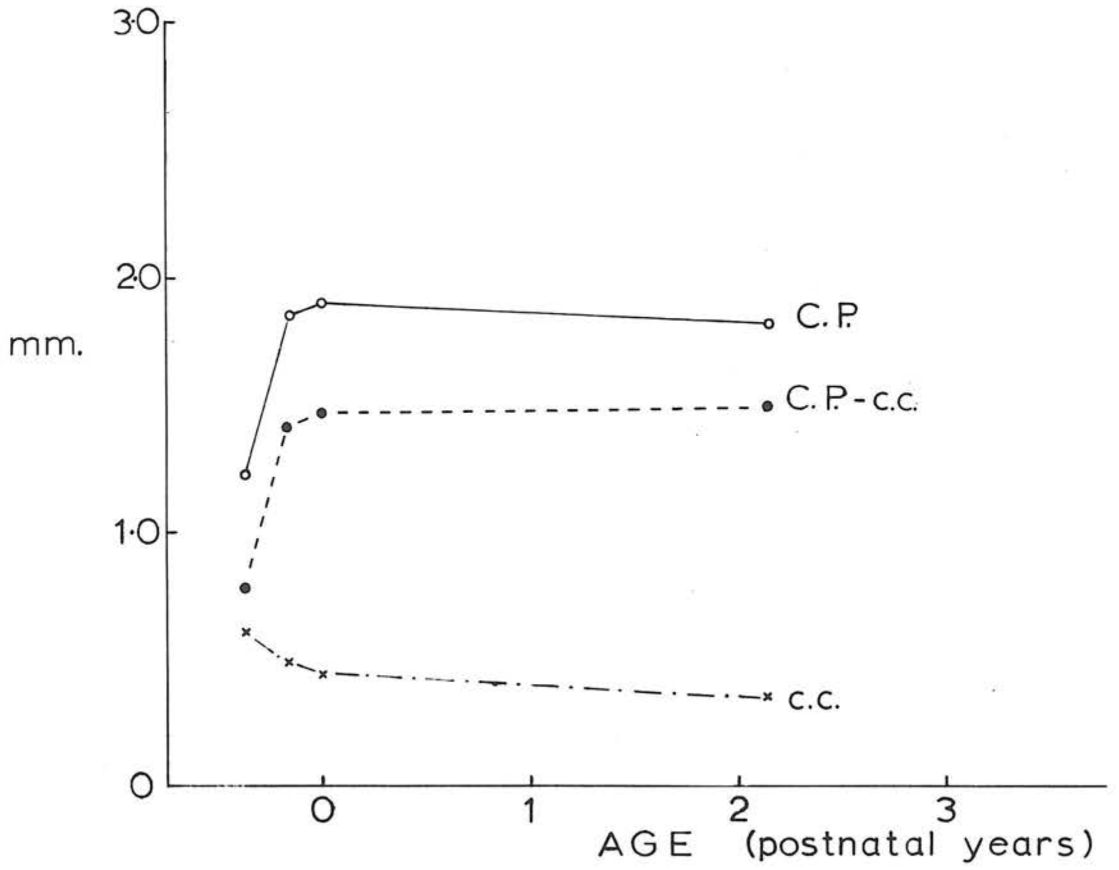

3·0
2·0
1·0
0
mm.
C. P.
C. P. - c.c.
c.c.
0
1
2
3
AGE (postnatal years)

Table 9d

Statistical Comparisons of Mean Thickness of 'Cartilage Layers'

(In Fetuses, New born, Infants and Children)

Age Group	Case Nos.	No. in Group	Mean Thickness of 'Cartilage Layers' (CPs - CCs)	S.D.	Student 't'	P
(i) L4-5						
Fetuses	3-19	15	1.85	0.22		
Newborn	21-34	12	2.45	0.45	4.506	< 0.001
Infants	38-45	8	1.92	0.32	2.868	< 0.01
Children under 3 years	46-52	6	1.60	0.15	2.304	< 0.05
Children over 3 years	53-59	6	2.27	0.18	7.118	< 0.001
(ii) T8-9						
Fetuses	4-17	6	1.41	0.16		
Newborn	20-24	5	1.74	0.15	3.546	< 0.01
Infants	40-46	4	1.63	0.26	0.8345	< 0.50
Children	52-59	5	1.27	0.14	2.6503	< 0.05
(iii) C 5-6						
Too few data are available for useful statistical comparison						

Mean 'cartilage layer' thicknesses of successive groups (as listed) are compared.

Table 9e

Comparrison of Cartilage Column Heights in the Cranial and Caudal Growth Plates of the same Vertebra

No.	Age	Vertebra	Average Cranial* Cartilage Column Height (mm)	Mean Height for Age (Group (mm)	Average Caudal* Cartilage Column Height (mm)	Mean Height for Age Group (mm)
3	25 w.	L4	0.38		0.40	
4	29 w.	L4	0.33		0.34	
6	30 w.	L3	0.32	0.36 ± 0.04	0.34	0.40 ± 0.05
8	31 w.	L4	0.40	(fetus)	0.47	(fetus)
17	35 w.	L3	0.40		0.43	
17	35 w.	L4	0.35		0.42	
21	40 w.	L4	0.27		0.26	
23	40 w.	L4	0.22	0.27 ± 0.03	0.23	0.26 ± 0.03
25	40 w.	L4	0.29	(newborn)	0.27	(newborn)
25	40 w.	L5	0.28		0.29	
39	3 m.	L4	0.21		0.20	
41	4 m.	L4	0.23		0.16	
42	4½m.	L5	0.23	0.24 ± 0.03	0.23	0.21 ± 0.04
44	6 m.	L4	0.30	(infants and	0.29	
46	1yr.2m.	L4	0.23	children)	0.18	
52	2yrs.8m.	L5	0.26		0.22	
53	3 yrs.	L5	0.23		0.22	

(* Average of 10 measurements made perpendicular to ossification front at regular intervals)

Table 9e (contd)

Statistical Comparison

Age Group	Cranial Column Heights	Caudal Column Heights	Difference	Mean Difference for Age Group
Fetuses	0.38	0.40	+ 0.02	
	0.33	0.34	+ 0.01	
	0.32	0.34	+ 0.02	0.037 ± 0.027
	0.40	0.47	+ 0.07	
	0.40	0.43	+ 0.03	
	0.35	0.42	+ 0.07	
Newborn	0.27	0.26	- 0.01	
	0.22	0.23	+ 0.01	-0.003 ± 0.015
	0.29	0.27	- 0.02	
	0.28	0.29	+ 0.01	
Infants and Children	0.21	0.20	- 0.01	
	0.23	0.16	- 0.07	
	0.23	0.23	0	
	0.30	0.29	- 0.01	-0.027 ± 0.024
	0.23	0.18	- 0.05	
	0.26	0.22	- 0.04	
	0.23	0.22	- 0.01	

Comparing the mean difference for each age group with 0

Age Group	$\bar{x}$	s^2	't'	P
Fetuses	0.037	0.0007	3.70	<0.0125
Newborn	-0.003	0.0002	0.36	<0.40
Infants and Children	-0.027	0.0006	2.82	<0.025

Thus (1) in fetuses the caudal cartilage columns are significantly taller than the cranial cartilage columns and (2) postnatally the situation is reversed.

Text-fig. 36

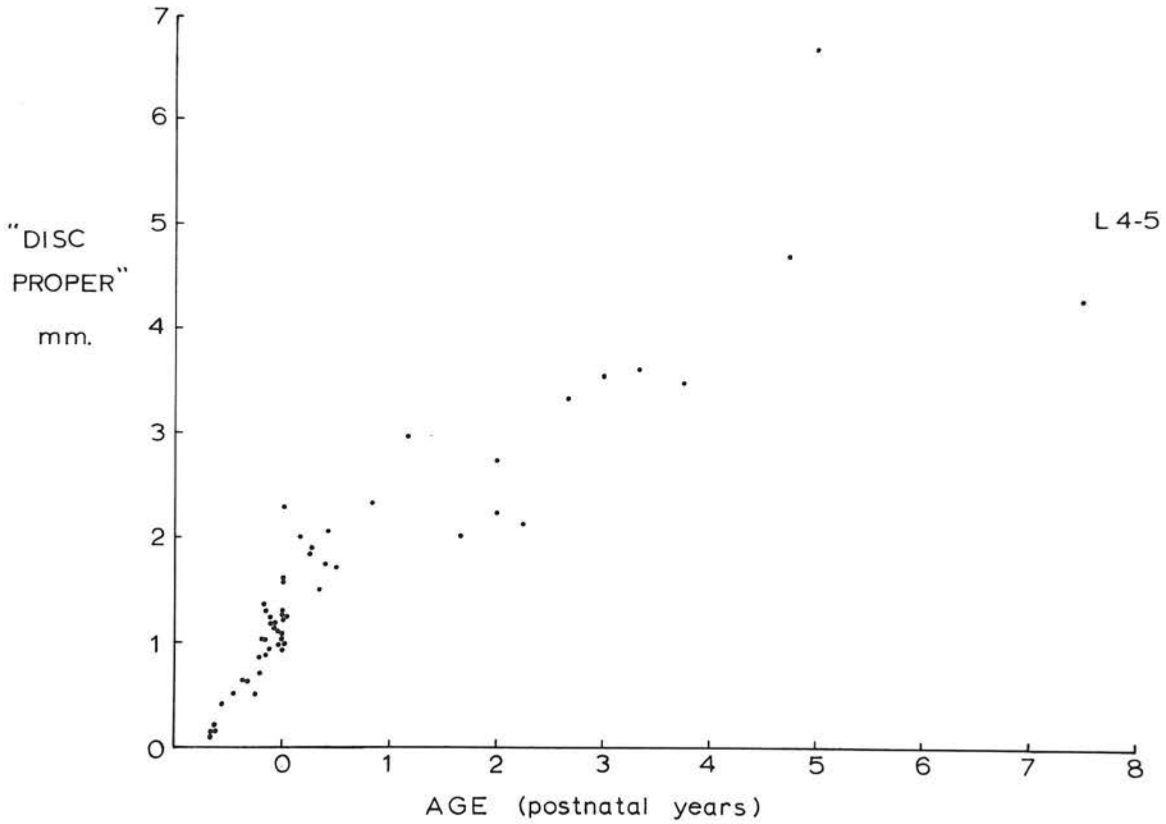
Scattergrams of 'disc proper' heights

(Table 9)

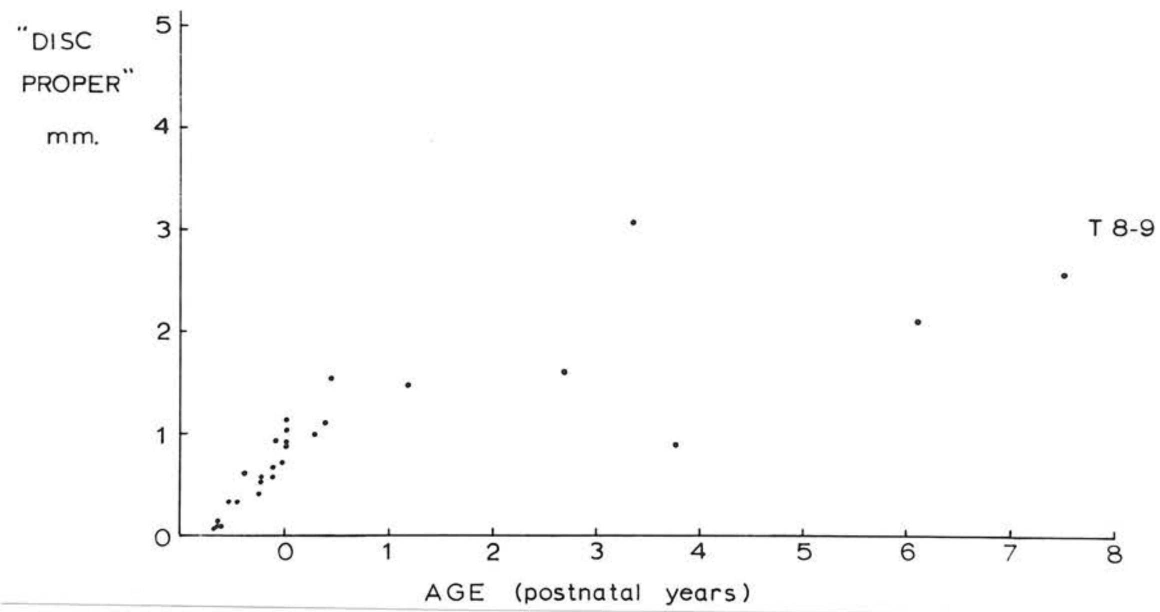
(a) L 4-5 'disc proper'

(b) T 8-9 'disc proper'

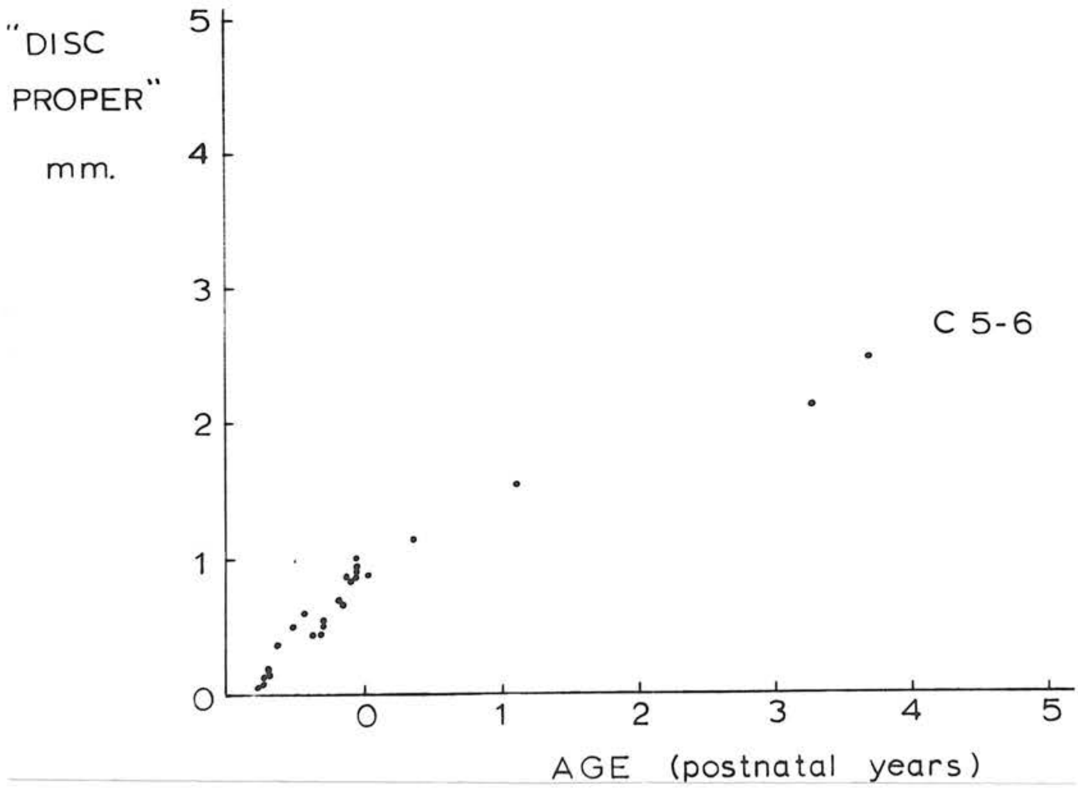
(c) C 5-6 'disc proper' (see next page)



"DISC PROPER" mm.
L 4-5
AGE (postnatal years)



"DISC PROPER" mm.
T 8-9
AGE (postnatal years)


"DISC PROPER" mm.
5
4
3
2
1
0
C 5-6
0
1
2
3
4
5
AGE (postnatal years)

Text-fig. 37

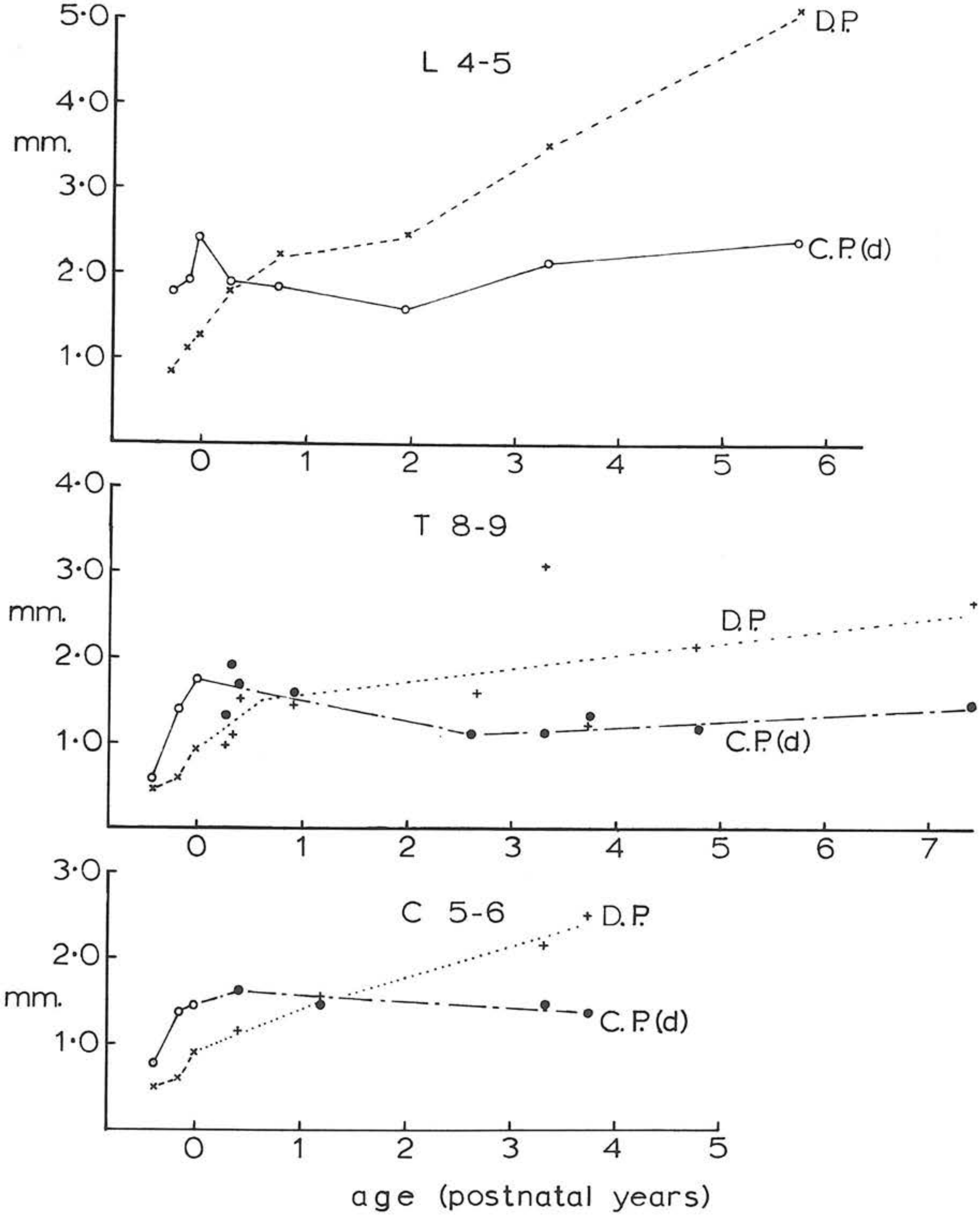
Comparison of 'disc proper' and 'cartilage layers' mean heights

D.P. = 'disc proper'
C.P.(d) = 'cartilage layers'
-o-, and -x- = mean values for groups
-●-, and -+- = individual values

(a) L 4-5

(b) T 8-9

(c) C 5-6



L 4-5
5·0
4·0
mm.
3·0
2·0
1·0
D.P
C.P.(d)
0
1
2
3
4
5
6
T 8-9
4·0
3·0
mm.
2·0
1·0
D.P
C.P.(d)
0
1
2
3
4
5
6
7
C 5-6
3·0
2·0
mm.
1·0
D.P
C.P.(d)
0
1
2
3
4
5
age (postnatal years)

In Table 10 the following abbreviations and terms are used:-

APD = Anteroposterior diameter
LD = Lateral diameter
AAF = Anterior anulus fibrosus
PAF = Posterior anulus fibrosus

TABLE 10a

HORIZONTAL DIMENSIONS OF DISC - L4-5

No.	Age	Disc			Notochordal Nucleus Pulposus		'Total' Anulus Fibrosus	
		APD	LD	APD/LD	APD	LD	AAF	PAF
E3	8 wks.	0.65	1.17	0.56	0.13	0.15	0.27	0.27
E4	9 wks.	0.95	1.45	0.66	0.20	0.15	0.30	0.42
1	18 wks.	3.20	5.10	0.63	0.90	1.35	0.90	1.40
2	22 wks.	5.10	7.88	0.65	1.10	3.20	1.90	2.20
E7	23 wks.	5.70	9.00	0.63	2.00	2.90	1.80	1.90
3	25 wks.	7.90	12.20	0.65	2.90	4.80	2.70	2.20
4	29 wks.	8.10	14.00	0.58	3.30	6.00	2.50	2.50
5	30 wks.	8.20	15.00	0.55	4.50	5.50	1.60	2.00
6	30 wks.	9.70	16.00	0.61	2.50	6.50	4.10	3.20
8	31 wks.	8.80	15.50	0.57	5.00	7.50	2.10	1.55
9	31 wks.	9.70	16.00	0.61	Abnormal nucleus pulposus			
15	34 wks.	8.70	15.50	0.56	5.70	7.00	1.45	1.50
16	35 wks.	11.50	19.00	0.61	5.75	10.20	3.60	1.80
17	35 wks.	10.70	18.10	0.59	5.20	9.80	3.65	1.90
21	40 wks.	11.40	20.40	0.56	4.00	9.50	5.30	2.00
22	40 wks.	12.50	23.00	0.54	6.00	12.00	4.20	2.30
27	40 wks.	11.25	21.00	0.54	6.50	11.50	2.90	1.70
29	40 wks.	13.20	23.00	0.57	7.50	10.10	3.70	1.90
31	40 wks.	11.00	20.00	0.55	6.50	12.50		
33	40 wks.	12.60	25.00	0.50	6.00	12.00	4.00	2.50
35	40 wks.	10.50	18.50	0.57	6.00	9.20	3.00	1.50
39	3 m.	12.50	22.40	0.56	8.50	10.50	1.50	2.50
40	3½ m.	12.50	22.50	0.56	9.00	12.00	1.50	1.70
41	4 m.	13.30	23.50	0.57	9.00	7.50	2.00	2.40
42	4½ m.	15.00	27.00	0.56	8.00	12.00	5.20	1.70
43	5 m.	16.80	27.50	0.61	11.00	14.30	3.80	2.00
44	6½ m.	14.20	24.40	0.58	10.30	14.20	2.20	1.60
45	10 m.	14.90	25.00	0.60	11.20	16.00	2.00	1.50
46	14 m.	19.20	32.00	0.60	12.30	16.30	4.00	2.80

TABLE 10a (contd.)

No.	Age	Disc APD	Disc LD	Disc APD/LD	Notochordal Nucleus Pulposus APD	Notochordal Nucleus Pulposus LD	'Total' Anulus Fibrosus AAF	'Total' Anulus Fibrosus PAF
48	1yr.8m	18.00	31.00	0.58	14.50	15.70	1.20	2.50
49	2 yrs.	17.00	31.00	0.55	11.60	12.00	2.00	3.30
50	2 yrs.	19.50	31.50	0.62	14.60	22.50	2.20	3.20
51	2yrs3m.	18.60	31.20	0.60	9.00	12.20	2.10	6.40
52	2yrs8m.	20.10	31.50	0.64	13.50	19.20	2.60	3.80
53	3 yrs.	23.00	36.00	0.64	No notochordal nucleus			
54	3yrs4m.	22.00	34.00	0.65	14.60	22.00	2.60	4.60
55	3yrs9m.	25.30	39.40	0.64	13.60	20.00	3.20	8.70
57	4yrs9m.	27.00	40.00	0.68	9.00	22.00	3.70	14.00
58	5 yrs.	26.00	38.00	0.68	12.50	18.00	5.00	7.60
59	7½yrs.	27.00	38.00	0.71	No notochordal nucleus			
60	10yrs.	31.00	42.00	0.74	No notochordal nucleus			
47	1yr.6m.	13.6	28.0	0.49	(physically retarded non-ambulant child)			

Table 10a

Means and Standard Deviations for nine Age Groups

(APD, LD, APD/LD Index and Increments in APD and LD)

LUMBAR

Case No.	n =	Mean Age and Range	Mean Disc Dimensions (mm)				Mean APD/LD Index	S.D.	APD & LD Increments (mm)		
			APD	S.D.	LD	S.D.			AP		L
E3 & 4	2	8.5 w. (8-9 w.)	0.80	-	1.31	-	0.61	-	-		-
1,2 & E7	3	21 w. (18-23w.)	4.67	1.30	7.33	2.00	0.64	0.01	3.87	<	6.02
3-17	9	31 w. (25-35w.)	9.26	1.24	15.70	2.02	0.59	0.03	4.59	<	8.37
21-35	7	40 w.	10.33	1.58	17.53	1.82	0.55	0.02	1.07	<	1.83
39-43	5	4.0m. (3-5 m.)	14.08	1.90	24.70	2.64	0.57	0.02	2.30	<	3.14
44-46	3	10.2m. ($6\frac{1}{2}$-14m)	16.10	2.71	27.13	4.23	0.59	0.01	2.02	<	2.43
48-51	4	2.0yrs. (1yr.8m-2yr.3m)	18.28	1.05	31.18	0.24	0.59	0.03	2.25	<	4.05
52-55	4	3.2yrs (2yr.8m-3yr.9m)	22.60	2.16	35.23	3.34	0.64	0.01	4.32	>	4.15
57-60	4	6.8yrs (4yr.9m-10yrs.)	27.75	2.22	39.50	1.50	0.70	0.03	5.15	>	4.27

TABLE 10b

HORIZONTAL DIMENSIONS OF DISC - T8-9

No.	Age	Disc			Notochordal Nucleus Pulposus		'Total' Anulus Fibrosus	
		APD	LD	APD/LD	APD	LD	AAF	PAF
E3	8 wks.	0.69	1.18	0.58	0.09	0.11	0.22	0.40
E4	9 wks	1.09	1.42	0.77	0.20	0.15	0.35	0.55
1	18 wks.	3.20	5.10	0.63	1.00	1.50	1.00	1.20
2	22 wks.	4.00	5.50	0.73	1.70	2.50	1.00	1.20
E7	23 wks.	5.00	6.40	0.78	1.70	1.90	2.20	1.10
4	29 wks.	7.10	10.20	0.70	2.60	3.20	2.80	1.60
* 6	30w.(a)	8.30	11.00	0.75	3.40	2.60	2.80	2.00
* 6	30w.(b)	8.20	10.40	0.79				
7	30 wks.	7.30	11.30	0.65	3.20	3.50	1.80	2.00
12	34 wks.	9.90	14.70	0.67	4.70	5.10	2.40	2.70
14	34 wks.	7.70	12.30	0.63	3.50	5.50	2.40	1.70
16	35 wks.	9.80	15.00	0.65	3.70	5.80	3.80	2.30
21	40 wks.	9.90	15.50	0.64	4.50	8.00	3.30	2.00
22	40 wks.	11.80	17.50	0.67	6.80	9.00	2.80	2.10
24	40 wks.	11.70	15.60	0.75	4.50	6.60	5.00	2.20
37	1 m.	11.00	18.00	0.61	Abnormal notochordal nucleus pulposus			
40	$3\frac{1}{2}$m.	11.50	16.50	0.70	8.00	9.00	1.70	1.70
*43	5 m.(a)	15.90	18.50	0.86	5.50	11.00	8.50	2.40
*43	5 m.(c)	15.60	20.00	0.78	5.00	11.00	8.50	2.00
*46	14 m.(a)	16.20	21.50	0.75	6.30	10.00	8.30	1.80
*46	14 m.(c)	15.80	21.50	0.73	4.40	9.40	9.40	1.70
52	2yrs.8m.	17.00	22.00	0.77	10.80	16.00	4.00	2.20
54	3yrs.4m.	19.00	26.50	0.72	10.50	13.00	5.50	3.00
55	3yrs.9m.	20.50	25.00	0.82	13.50	16.00	5.00	1.30
57	4yrs.9m.	22.00	28.00	0.79	6.00	10.00	9.50	6.50
59	7yrs.6m.	22.00	25.00	0.88	No notochordal nucleus pulposus			

* (a) = T8-9 (b) = T7-8 (c) = T9-10

Table 10b

Means and Standard Deviations for seven Age Groups

(APD, LD, APD/LD Index and Increments in APD and LD)

THORACIC

Case No.	n=	Mean Age and Range	Mean Disc Dimensions (mm) APD	S.D.	LD	S.D.	Mean APD/LD Index	S.D.	APD & LD Increments (mm) AP	L
E3 & 4	2	8.5 w. (8-9 w.)	0.89	-	1.30	-	0.68	-	-	-
1,2,E7	3	21 w. (18-23w.)	4.06	0.90	5.67	0.65	0.71	0.08	3.67	5.06
4 - 16	7	32 w. (29-35w.)	8.33	1.13	12.13	1.98	0.69	0.06	4.27	6.46
21-37	4	40 w. (40w-1m.)	11.10	0.88	16.65	1.29	0.67	0.06	2.77	4.52
40-46	5	8.3 m. (3½-14m.)	15.00	1.97	19.60	2.13	0.76	0.06	3.90	2.95
52-55	3	3.3yrs. (2yrs.8m.-3yrs.9m.)	18.83	1.76	24.50	2.29	0.77	0.05	3.83	4.90
57&59	2	6.1yrs. (4yrs.9m.-7yrs.6m.)	22.5	0.50	27.00	2.00	0.83	0.06	3.67	2.50

TABLE 10c

HORIZONTAL DIMENSIONS OF DISC - C5-6

No.	Age	Disc			Notochordal Nucleus Pulposus		'Total' Anulus Fibrosus	
		APD	LD	APD/LD	APD	LD	AAF	PAF
E3	8 wks.	0.62	1.15	0.54	0.07	0.08	0.24	0.31
E4	9 wks.	0.96	1.32	0.73	0.13	0.11	0.34	0.50
1	18 wks.	2.70	4.50	0.60	0.50	0.50	0.80	1.40
2	22 wks.	3.50	5.50	0.64	1.20	1.00	0.90	1.30
E7	23 wks.	3.60	5.60	0.64	0.50	0.90	1.20	2.00
3	25 wks.	5.50	9.30	0.59	1.20	1.30	1.30	3.10
4	29 wks.	5.50	9.50	0.58	1.10	1.80	1.50	2.80
6	30 wks.	6.20	10.00	0.62	0.50	1.40	1.40	4.20
12	34 wks.	7.70	11.70	0.66	3.20	5.00	2.60	1.90
14	34 wks.	6.00	10.10	0.59	0.50	1.00	1.50	4.00
16	34 wks.	7.40	12.30	0.60	3.50	6.50	2.00	1.70
17	35 wks.	6.90	11.00	0.63	1.40	2.00	3.50	3.50
21	40 wks.	6.80	12.00	0.57	2.00	3.40	2.80	2.00
22	40 wks.	8.20	13.50	0.61	4.10	5.00	2.00	2.10
23	40 wks.	7.60	13.00	0.58	3.90	4.50	1.90	1.80
24	40 wks.	7.70	13.50	0.57	No notochordal nucleus			
25	40 wks.	7.70	12.60	0.61	3.00	3.60	1.80	2.80
37	1 m.	7.80	13.50	0.58	2.20	3.00	2.40	3.20
43	5 m.	9.60	16.80	0.57	No notochordal nucleus			
46	14 m.	9.80	17.70	0.55	4.80	7.50	2.30	2.70
54	3yrs4m.	11.01	17.5	0.63	No measureable notochordal nucleus pulposus			
55	3yrs9m.	11.06	19.5	0.59	7.70	6.50	1.30	2.60

Table 10c

Means and Standard Deviations for six Age Groups

(APD, LD APD/LD Index and Increments in APD and LD)

CERVICAL

Case No.	n =	Mean Age and Range	Mean Disc Dimensions (mm)				Mean APD/LD Index	S.D.	APD & LD Increments (mm)	
			APD	SD	LD	S.D.			AP	L
E3 & 4	2	8.5 w. (8-9w)	0.79	0.24	1.24	0.12	0.64	-	-	-
1,2,E7	3	21 w. (18-25w.)	3.27	0.49	5.20	0.61	0.63	0.02	2.48	3.96
3 - 17	9	31.6w.	6.46	0.89	10.56	1.14	0.61	0.03	3.19	5.36
21-25	5	40 w.	7.60	0.50	12.92	0.64	0.59	0.02	1.14	2.36
37-46	3	6.7 m. (1-14m)	9.07	1.10	16.00	2.21	0.57	0.02	1.47	3.08
54&55	2	3-5yrs. (3yrs.4m-3yrs.9m)	11.35	0.35	18.50	1.41	0.61	0.03	2.28	2.50

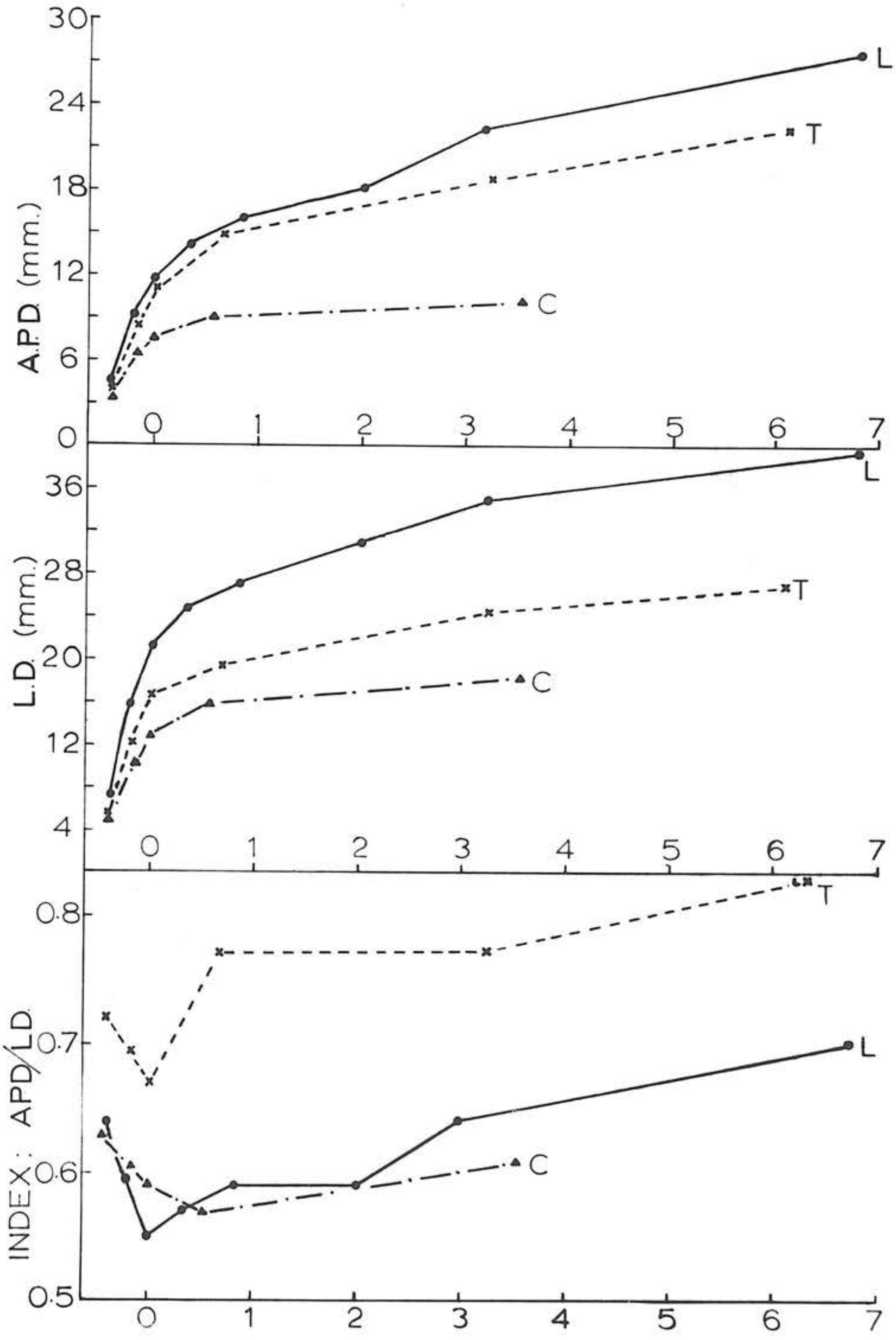
Text-fig. 38

Horizontal dimensions of postmortem discs

(a) Mean anteroposterior diameters of L 4-5 (L), T8-9 (T) and C 5-6 (C)

(b) Mean lateral diameters of L 4-5 (L), T 8-9 (T) and C 5-6 (C)

(c) Mean Indices $\frac{\text{A.P.D.}}{\text{L.D.}}$ for L 4-5, T 8-9 and C 5-6



A.P.D. (mm.)
30
24
18
12
6
0
L
T
C
0 1 2 3 4 5 6 7
L.D. (mm.)
36
28
20
12
4
INDEX: APD/LD
0.8
0.7
0.6
0.5

Means and Standard Deviations
for 'nucleus' APD and 'total anulus' (AAF & PAF)
(from Table 10a for Text - Fig. 39)

Group	Case No.	n =	Mean Age	Mean 'nucleus' (mm) APD	S.D.	Mean 'total anulus' (mm) (AAF & PAF)	S.D.
1	E3 & 4	2	8.5 w.	0.17	-	0.64	-
2	1,2,E7	3	21 w.	1.33	0.59	3.36	0.95
3	3 - 17	8	31 w.	4.35	0.13	4.79	1.37
4	21-35	6	40 w.	6.07	1.05	5.83	1.13
5	39-43	5	4 m.	9.10	1.14	4.86	1.48
6	44-46	3	10 m.	11.27	1.00	4.70	1.82
7	48-51	4	2 yrs.	12.43	2.67	5.73	2.00
8	52-55	3	3.2yrs	13.90	0.61	8.50	2.97
9	57&58	2	5 yrs.	10.75	2.50	15.15	3.60

Statistical Comparison Newborn and Infant 'Anulus'

Case No.	n =	Mean Age	Mean 'Anulus' (mm) (AAF & PAF)	S.D.	t =	P
21 - 35	6	40 w.	5.83	1.13	1.892	<0.10
39 - 45	7	5.3 m.	4.51	1.35		

Note that in groups 1 and 2, AF > NP
3 and 4, AF ≈ NP
5 - 8, AF < NP

Text-fig. 39

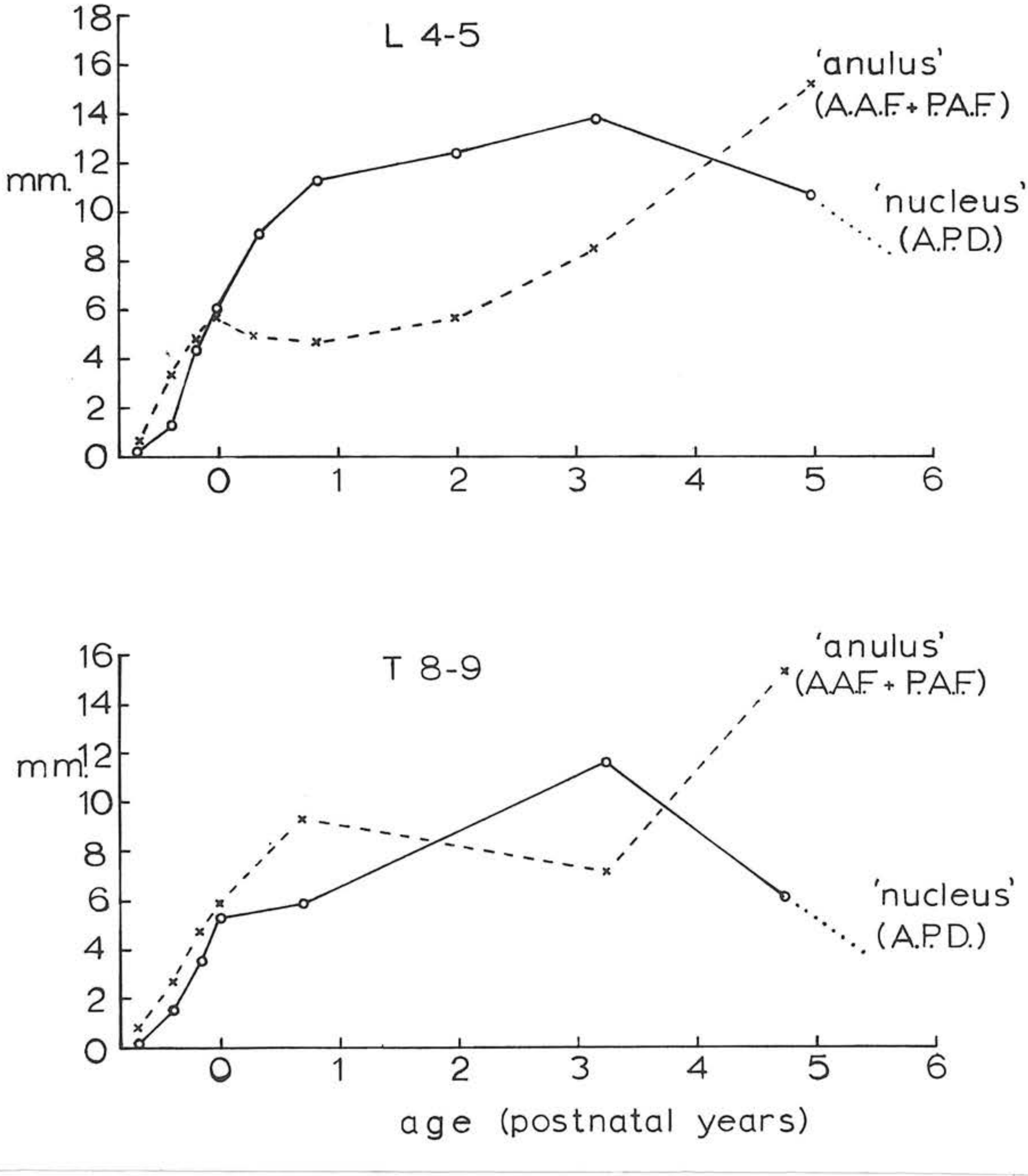
Comparison of the thickness of the 'anulus' and the anteroposterior extent of the notochordal nucleus pulposus in the median plane

'anulus' = means of the sum of the anterior anulus fibrosus and posterior anulus fibrosus (including the inner cell zones)

'nucleus' = means of the anteroposterior diameter of the notochordal nucleus pulposus

(a) L 4-5

(b) T 8-9



L 4-5
18
16
14
12
10
8
6
4
2
0
mm.
0 1 2 3 4 5 6
'anulus'
(A.A.F.+P.A.F.)
'nucleus'
(A.P.D.)
T 8-9
16
14
12
10
8
6
4
2
0
mm.
0 1 2 3 4 5 6
'anulus'
(A.A.F.+P.A.F.)
'nucleus'
(A.P.D.)
age (postnatal years)

Table 11a

Horizontal Dimensions of the 'Disc Proper', measured in the median plane (in mm) from the Notochord or from its remnant in the Cartilage Plates, A - to the anterior border of the 'Disc Proper' and B - to the posterior border of the 'Disc Proper'

No.	Age (ante-natal weeks)	L 4-5		T 8-9		C 5-6	
		A	B	A	B	A	B
E1	7w. (20mm)	0.31	0.33	0.27	0.38	0.28	0.33
E5	9w. (30mm)	0.40	0.40	0.36	0.55	0.42	0.48
E6	13w. (75mm)	0.90	1.30	0.85	1.45	0.80	1.05
1	18w.	1.4	1.8	1.4	1.8	1.2	1.5
2	22w.	2.4	2.6	1.7	2.3	1.6	1.9
E7	23w.	2.6	3.0	2.2	2.7	1.4	2.2
3	25w.	3.5	4.4	-	-	2.5	3.0
4	29w.	3.3	4.6	2.9	4.2	2.2	3.3
5	30w.	3.0	5.0	-	-	-	-
6	30w.	4.2	5.4	3.5	4.6	2.8	3.3
7	30w.	-	-	2.9	4.5	-	-
8	31w.	4.1	4.7	-	-	-	-
11	32w.	3.9	5.1	-	-	-	-
12	34w.	5.8	6.0	4.4	5.5	3.1	4.5
14	34w.	-	-	3.4	4.4	2.9	3.2
15	34w.	2.9	5.8	-	-	-	-
16	35w.	5.4	6.1	-	-	3.7	3.6
17	35w.	5.0	5.7	-	-	3.5	3.4
19	36w.	4.8	5.4	-	-	-	-
20	40w.	5.3	6.0	5.1	5.8	4.0	3.2
21	40w.	5.9	5.9	4.4	5.5	3.5	3.3
22	40w.	5.3	7.1	4.8	7.0	4.0	4.2
23	40w.	5.8	6.5	3.7	4.7	3.6	4.0
24	40w.	-	-	5.2	6.5	4.1	3.5
25	40w.	-	-	-	-	3.8	3.9
27	40w.	5.2	6.0	-	-	-	-
29	40w.	6.8	6.5	-	-	-	-
35	40w.	4.7	5.8	-	-	-	-

Table 11a (contd.)

No.	Age (ante-natal weeks)	L 4-5		T 8-9		C 5-6	
		A	B	A	B	A	B
38	2 m.	4.7	6.7	-	-	-	-
40	$3\frac{1}{2}$m.	-	-	5.1	6.3	-	-
41	4 m.	5.8	7.5	-	-	-	-
42	$4\frac{1}{2}$m.	7.0	8.0	-	-	-	-
43	5 m.	7.6	9.2	7.2	8.8	4.9	4.7
44	6 m.	6.4	7.6	-	-	-	-
45	10 m.	6.6	8.3	-	-	-	-
46	14 m.	-	-	7.8	8.4	5.6	4.2
48	1 yr. 8 m.	8.2	10.3	-	-	-	-
49	2 yrs.	8.4	9.5	-	-	-	-
50	2 yrs.	9.0	10.6	-	-	-	-
51	2 yrs.3 m.	7.7	10.7	-	-	-	-
52	2 yrs.8 m.	-	-	7.8	9.2	-	-
54	3 yrs.4 m.	10.0	12.2	9.3	9.9	6.1	5.0
55	3 yrs.9 m.	-	-	10.6	9.7	5.2	6.4
57	4 yrs.9 m.	12.4	14.1	10.7	11.1	-	-
59	7 yrs.6 m.	-	-	12.0	10.0	-	-
60	10 yrs.	15.3	16.2	-	-	-	-

Table 11b

Horizontal Dimensions of Vertebral Bodies in mm. measured in the Median Plane from the Notochord, Mucoid Streak or Cartilage Nodules
(A - to anterior border, B - to posterior border)

No.	Age (ante-natal weeks)	L4 A	L4 B	T8 A	T8 B	C5 A	C5 B
E1	7w. (20mm)	0.31	0.33	0.28	0.40	0.28	0.33
E5	9w. (30mm)	0.40	0.40	0.40	0.54	0.42	0.48
E6	13w. (75mm)	0.80	0.93	0.70	1.35	0.65	1.03
1	18w.	1.5	2.0	1.2	1.6	1.4	1.4
2	22w.	2.4	2.5	1.4	2.3	1.7	1.9
4	29w.	-	-	3.2	4.2	-	-
5	30w.	4.5	3.6	-	-	-	-
6	30w.	5.0	4.0	3.9	3.7	-	-
7	30w.	-	-	3.7	3.7	-	-
8	31w.	-	-	4.2	3.6	-	-
16	35w.	-	-	4.5	5.0	-	-
19	36w.	5.4	3.9	-	-	-	-
21	40w.	6.2	5.0	4.9	5.4	-	-
25	40w.	-	-	5.4	5.4	-	-
32	40w.	7.0	5.5	-	-	-	-
37	1m.	6.6	6.6	4.5	4.6	-	-
40	3m.	-	-	5.0	4.9	-	-
45	10m.	8.0	7.2	-	-	-	-
46	1yr. 2m.	-	-	7.3	7.5	-	-
54	3yr. 4m.	-	-	9.8	8.9	-	-
59	7yr. 6m.	-	-	11.1	9.1	-	-

Table 11c

Measurements to the anterior and posterior surfaces of the Vertebral Column (in the median plane) from the centre of Schmorl's nodes

1	Adult	L3-24mm	13mm	-	-	-	-
2	"	L4-21mm	15mm	-	-	-	-
3	"	L5-20mm	15.5mm	-	-	-	-
4	"	T9	-	27mm	10.5mm	-	-
5	"	L4-22mm	13.5mm	-	-	-	-
6	"	T8	-	16mm	10 mm	-	-
6	"	T10	-	21mm	11 mm	-	-

Table 11

Means and Increments (from data in Tables 11 (a), (b) and (c))

(i) Lumbar

	No.	Mean Age	Mean Distance to Anterior Border (mm)	Mean Distance to Posterior Border (mm)	Increments (mm) A	Increments (mm) B
Vertebral Body L4	E1 & E5	8w. a.n.	0.36	0.37	-	-
	E6	13w. a.n.	0.80	0.93	0.44	0.56
	1 & 2	20w. a.n.	1.95	2.25	1.15	1.32
	5,6,8	30w. a.n.	4.57	3.73	2.62	1.48
	19,21,32 & 37	40w. a.n.	6.30	5.25	1.73	1.52
	45	10m. p.n.	8.0	7.2	1.70	1.95
	4 Adults (Schmorl's nodes)		21.8	14.3	13.8	7.1
'Disc Proper' L4-5	E1 & E5	8w. a.n.	0.36	0.37	-	-
	E6	13w. a.n.	0.90	1.30	0.54	0.93
	1,2,E7	21w. a.n.	2.1	2.5	1.2	1.2
	3-6,8,11 12,15-17	31w. a.n.	4.1	5.3	2.0	2.8
	19 - 35	40w. a.n.	5.5	6.2	1.4	0.9
	38,41-45	5m. p.m.	6.4	7.9	0.9	1.7
	48-51	2 yrs.	8.3	10.3	1.9	2.4
	54,57,60	6 yrs.	12.6	14.2	4.3	3.9
	4 Adults (Schmorl's nodes)		21.8	14.3	9.2	0.1

Table 11

Means and Increments

(ii) Thoracic

	No.	Mean Age	Mean Distance to Anterior Border (mm)	Mean Distance to Posterior Border (mm)	Increments (mm) A	B
Vertebral Body T8	E1 & E5	8w. a.n.	0.34	0.47	-	-
	E6	13w. a.n.	0.70	1.35	0.26	0.63
	1 & 2	20w. a.m.	1.30	1.95	0.70	0.85
	4,6,7	30w. a.n.	3.60	3.87	2.30	1.92
	16-40	2.5w.	4.86	5.06	1.26	1.19
	46	14m.	7.3	7.5	2.44	2.45
	54	3yrs. 3m.	9.8	8.9	2.5	1.4
	59	7yrs. 6m.	11.1	9.1	1.3	0.2
	3 Adults (Schmorl's nodes)		21.3	10.5	10.2	1.4
'Disc Proper' T8-9	E1 & E5	8w. a.n.	0.32	0.47	-	-
	E6	13w. a.n.	0.85	1.45	0.53	0.98
	1,2,E7,	21w. a.n.	1.77	2.27	0.92	0.82
	4,6,7,12 & 14	32w. a.n.	3.45	4.80	1.68	2.53
	20 to 24	40w. a.n.	4.60	6.25	1.15	1.45
	40,43,46	7½m. p.n.	6.67	7.80	2.07	1.55
	52,54,55	3yrs. 3m.	9.27	9.63	2.60	1.83
	57 & 59	6 yrs.	11.35	10.55	2.08	0.92
	3 Adults (Schmorl's nodes)		21.3	10.5	10.0	-

Table 11

Means and Increments

(iii) Cervical

	No.	Mean Age	Mean Distance to Anterior Border (mm)	Mean Distance to Posterior Border (mm)	Increments A	Increments B
Vertebral Body C5	E1 & E5	8w. a.n.	0.35	0.41	-	-
	E6	13w. a.n.	0.65	1.03	0.30	0.62
	1 & 2	20w. a.n.	1.53	1.60	0.88	0.57
'Disc Proper' C5-6	E1 & E5	8w. a.n.	0.35	0.41	-	-
	E6	13w. a.n.	0.80	1.15	0.45	0.74
	1,2,E7	21w. a.n.	1.40	1.90	0.60	0.85
	3,4,6, 12,14, 16,17	31w. a.n.	2.96	3.47	1.56	1.57
	20-25	40w. a.n.	3.83	3.68	0.87	0.21
	43&46	10m. p.n.	5.25	4.45	1.42	0.77
	54&55	3yrs.6m.	5.65	5.70	0.40	1.25

Conclusions

Let 'A' = anterior growth from the notochord

Let 'B' = posterior growth from the notochord

Then (i) B > A in all vertebrae and discs from 8 to 13 weeks.

(ii) A > B in thoracic vertebrae and discs during childhood, in lumbar discs and probably in lumbar vertebrae during childhood

(iii) The transition from (i) to (ii) takes place at an earlier stage (fetal life) in vertebrae than in discs (post-natal life)

Text-fig. 40

Mean horizontal dimensions (in the median plane) from the notochord or its remnants to the anterior or posterior surface of the vertebral column

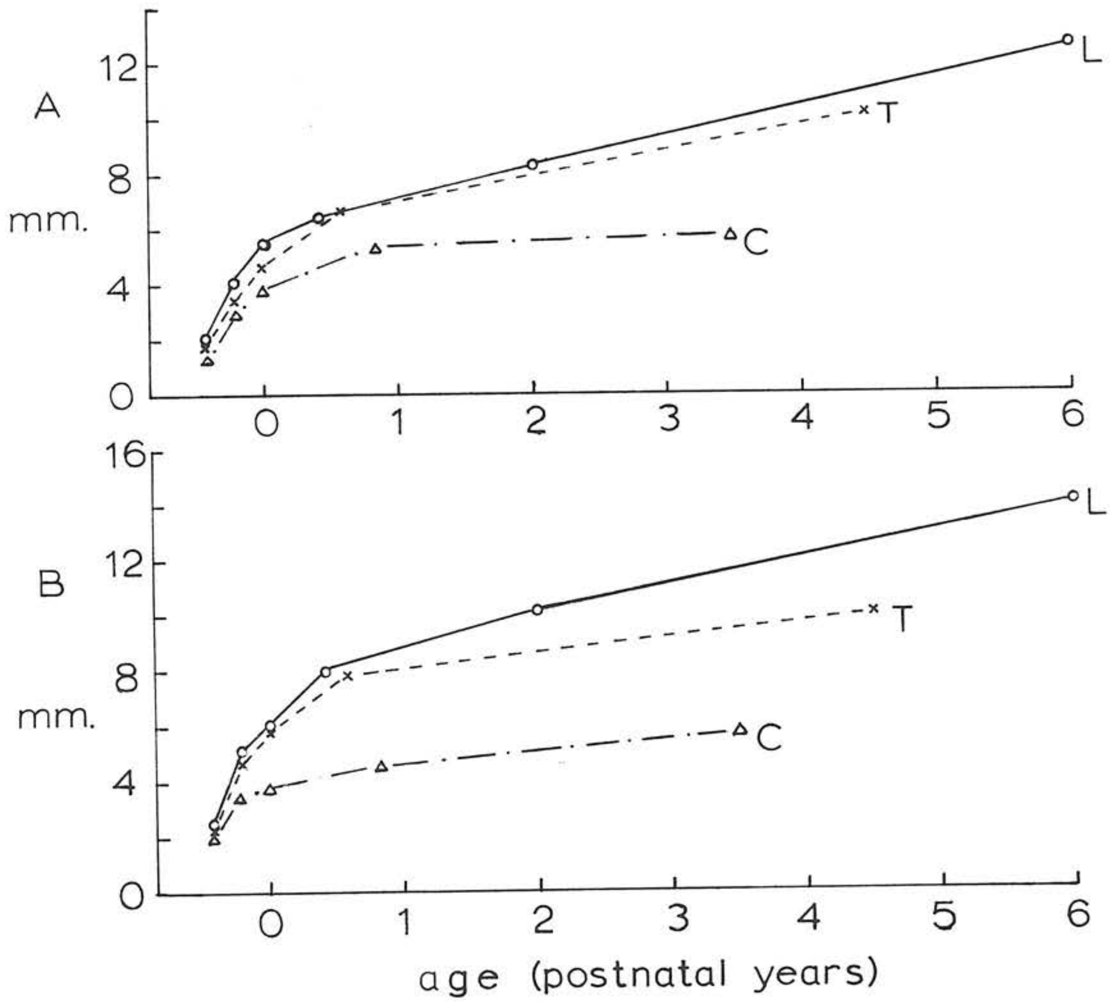
(Tables 11(a) and (b))

(a) A = distance from line joining notochordal remnants in the 'cartilage layers' to the anterior surface of the disc, in L 4-5 (L), T 8-9 (T) and C 5-6 (C).

(b) B = distance from line joining notochordal remnants in the 'cartilage layers' to the posterior surface of the disc, in L 4-5, T 8-9 and C 5-6.

(c) A = distance from vertical line through centre of cartilage nodules to the anterior surface of the vertebral body T 8.

B = distance from the same vertical line to the posterior surface of the vertebral body T 8.


A
B
12
8
4
0
16
mm.
L
T
C
0
1
2
3
4
5
6
age (postnatal years)

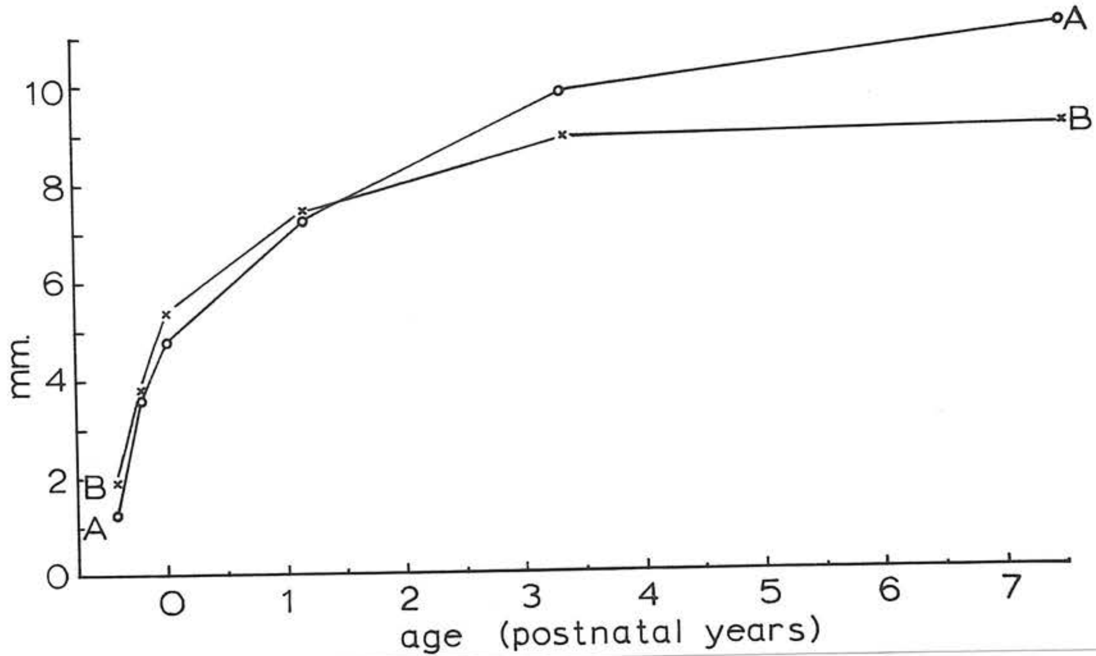

10
8
6
4
2
0
mm.
A
B
0
1
2
3
4
5
6
7
age (postnatal years)

Table 12a

Volume of the Lumbar Notochordal Nucleus Pulposus

(NC. cells in mucoid matrix)

Age Group	No.	Age	Disc	Volume (mm^3) (Planimetry)	Mean Volume for Group (mm^3)
Embryos	E3&4	8-9 w.	L	-	0.0023 (calculated) from average linear dimensions
Fetuses from 18-22 w.	1	18 w.	L	1.5	2.1
	2	22 w.	L	2.7	
Fetuses from 25-35 w.	3	25 w.	L4-5	4.0	20.9 ± 12.7 (Nos. 3-17)
	4	29 w.	L4-5	7.5	
	5	30 w.	L3-4	26.0	
	6	30 w.	L4-5	6.0	
	8	31 w.	L4-5	22.0	
	9	31 w.	L3-4	8.0	
	10	32 w.	L3-4	40.0	
	11	32 w.	L3-4	18.0	
	12	33 w.	L4-5	21.0	
	13	34 w.	L3-4	28.0	
	15	34 w.	L3-4	40.0	
	16	35 w.	L4-5	15.0	
	17	35 w.	L4-5	36.0	
Newborn	22	40 w.	L4-5	42.0	45.4 ± 10.2 (Nos.22-35)
	23	40 w.	L4-5	37.0	
	25	40 w.	L4-5	45.0	
	26	40 w.	L4-5	38.0	
	27	40 w.	L4-5	33.0	
	29	40 w.	L4-5	62.0	
	32	40 w.	L3-4	42.0	
	34	40 w.	L3-4	50.0	
	35	40 w.	L3-4	60.0	
Infants from 2 - 5 m.	38	2 m.	L3-4	83.0	86.3 ± 20.3 (Nos.38-43)
	39	3 m.	L4-5	90.0	
	40	3½ m.	L4-5	86.0	
	41	4 m.	L4-5	50.0	
	42	4½ m.	L4-5	99.0	
	43	5 M.	L4-5	110.0	

Table 12a (contd.)

Age Group	No.	Age	Disc	Volume (mm^3) (Planimetry)	Mean Volume for Group (mm^3)
Children from 10m. to 2yrs. 8m.	45 46 48 49 50 52	10 m. 14 m. 1yr8m. 2yrs. 2yrs. 2yr8m.	L3-4 L4-5 L4-5 L4-5 L4-5 L4-5	250.0 230.0 270.0 210.0 330.0 260.0	258.3 ± 41.2 (Nos.45-52)
Children from 3yrs 4m. to 5 yrs.	54 55 56 57 58	3yr4m. 3yr9m. 4 yrs. 4yr9m. 5 yrs.	L4-5 L4-5 L3-4 L4-5 L4-5	490.0 470.0 440.0 220.0 1005.0	525.0 ± 289.4 (Nos.54-58)
	59 60	$7\frac{1}{2}$yrs. 10yrs.	L4-5 L4-5	- -	

Table 12b

Volume of the Thoracic Notochordal Nucleus Pulposus

Age Group	No.	Age	Disc	Volume (mm^3) (Planimetry)	Mean Volume for Group (mm^3)
Embryos	E3&4	8-9 w.	T	-	0.0015 (calculated) from average linear dimensions
Fetuses from 18-22 w.	1 2	18 w. 22 w.	T T	0.30 0.60	0.45
Fetuses from 29-30 w.	4 6	29 w. 30 w.	T8-9 T8-9	2.6 2.8	2.7
Newborn	21 22 24	38 w. 40 w. 40 w.	T8-9 T8-9 T8-9	7.8 16.0 6.5	10.0
Infants	40 43 43 46	3½ m. 5 m. 5 m. 10 m.	T8-9 T8-9 T9-10 T8-9	31.0 43.0 70.0 42.0	46.5
Children	54 55	3yr4m 3yr9m	T8-9 T8-9	170.0 150.0	160.0

Table 12c

Volume of the Cervical Notochordal Nucleus Pulposus

Age Group	No.	Age	Disc	Volume (mm^3) (Planimetry)	Mean Volume for Group (mm^3)
Embryos	E3&4	8-9 w.	C5-6	-	0.0007 (calculated) from average linear dimensions
Fetuses from 18-22 w.	1 2	18 w. 22 w.	C5-6 C5-6	0.08 0.14	0.11
Fetuses from 25-35 w.	3 4 6 14 16	25 w. 29 w. 30 w. 34 w. 35 w.	C5-6 C5-6 C5-6 C5-6 C5-6	0.36 0.52 0.40 1.0 3.2	1.10
Newborn	21 22 23 24 37	38 w. 40 w. 40 w. 40 w. 1 m.	C5-6 C5-6 C5-6 C5-6 C5-6	0.40 9.2 5.1 0 1.8	3.3 (wide variation)
Infants and Children	43 46 54 55	5 m. 14 m. 3yr4m 3yr9m	C5-6 C5-6 C5-6 C5-6	0 29.0 3.3 43.0	18.8 (wide variation)

Summary

Comparative Increases in Notochordal Nucleus Pulposus Volume (approximate) in Three Regions

	Volume in 8-9 w. embryo	Volume in Newborn Infant	Prenatal Increase	Volume in 3yrs. 9m. Child	Total Increase
Lumbar	$0.0023mm^3$	$45mm^3$	X20,000	$470mm^3$	X200,000
Thoracic	$0.0015mm^3$	$15mm^3$	X10,000	$150mm^3$	X100,000
Cervical	$0.0007mm^3$	$33mm^3$	X 5,000	$43mm^3$	X 60,000

Regional differences, apparent in embryos, are accentuated during development

Table 13

Index of Notochordal Cell Numbers

(NCNP = Notochordal Nucleus Pulposus)
NC = Notochordal

No.	Age	Disc	(a) Nuclear Count per 100 grid squares	(b) Percentage of NCNP occipital by cells	(c) Volume of NCNP (ml)	(a)x(b)x(c) Index of number of NC cells
1	18w.	L	115/100	26%	0.0015	0.05x
2	22w.	L	155/100	40%	0.0027	0.17x
3	25w.	L4-5	121/100	51%	0.0040	0.21x
4	29w.	L4-5	120/100	29%	0.0075	0.26x
6	30w.	L4-5	95/100	40%	0.0060	0.23x
8	31w.	L4-5	138/100	14%	0.0220	0.43x
9	31w.	L3-4	116/100	27%	0.0080	0.25x
25	40w.	L3-4	95/100	20%	0.045	0.86x
29	40w.	L4-5	137/100	12%	0.062	1.02
32	40w.	L3-4	141/100	13.3%	0.042	0.79x
34	40w.	L4-5	125/100	15%	0.050	0.94x
39	3m.	L4-5	88/100	16%	0.090	1.27x
40	$3\frac{1}{2}$m.	L4-5	120/100	8%	0.086	0.83x
41	4m.	L4-5	140/100	20%	0.050	1.40x
42	$4\frac{1}{2}$m.	L4-5	66/100	16.5%	0.099	1.08x
43	5m.	L4-5	72/100	16%	0.111	1.28x
45	10m.	L3-4	77/100	7.5%	0.250	1.44x
46	14m.	L4-5	80/100	3.3%	0.230	0.61x
50	2yr.	L4-5	101/100	2.9%	0.330	0.97x
54	3yr.4m	L4-5	65/100	6.6%	0.490	2.10x

Text-fig. 41

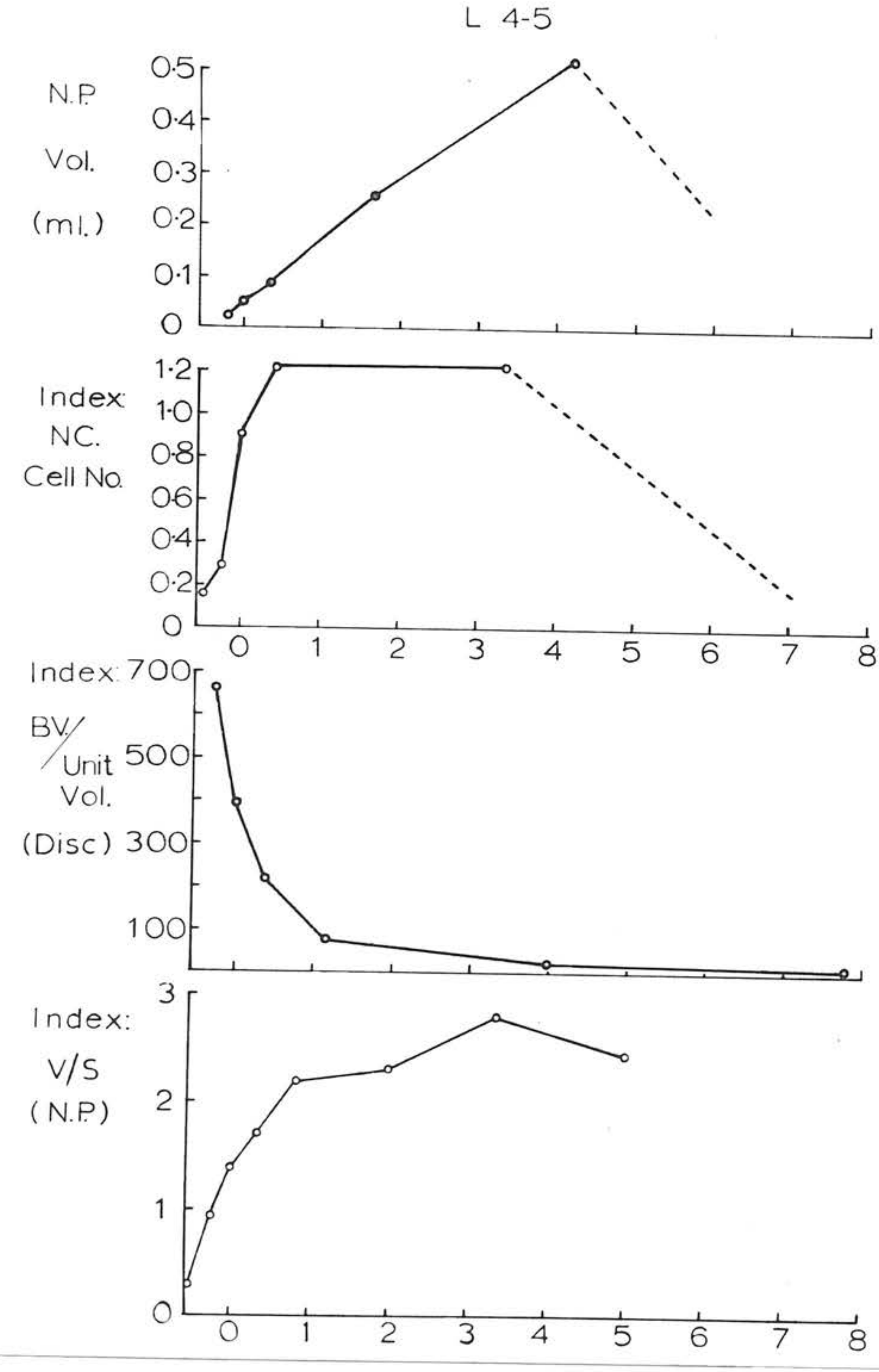
Age changes in the disc

(a) Mean volume of the notochordal nucleus pulposus of L 4-5 (planimetry). (Table 12(a)).

(b) Mean index of notochordal cell number in L 4-5 notochordal nucleus pulposus (Table 13).

(c) Vascular canal count in the 'cartilage layers' per unit volume of the 'disc proper' (Table 23).

(d) The relation of the volume of the notochordal nucleus pulposus (V) to its surface area (S), (Table 16)


L 4-5
N.P. Vol. (ml.)
0·5
0·4
0·3
0·2
0·1
0
Index: NC. Cell No.
1·2
1·0
0·8
0·6
0·4
0·2
0
0 1 2 3 4 5 6 7 8
Index: BV/Unit Vol. (Disc)
700
500
300
100
Index: V/S (N.P)
3
2
1
0
0 1 2 3 4 5 6 7 8

Age in years

Table 14

Volume of L4-5 'Disc Proper', Notochordal Nucleus Pulposus (NCNP) and Anulus Fibrosus (including 'lamellal anulus' (A.F.) and 'inner cell zone' (F.C.))

(see materials and methods pages 55-56, and Text-fig. 11)

No.	Age	Volume of 'Disc Proper' (ml)	Volume of NCNP (ml)	NCNP 'Disc Proper' %	Volume of 'A.F.' * (ml)	'AF' 'Disc Proper' %	Volume of 'F.C.' * (ml)	'F.C.' 'Disc Proper' %
4	29 w.	0.160	0.008	5.0%	0.135	84.4%	0.018	11.3%
8	31 w.	0.243	0.022	9.0%	0.177	72.8%	0.039	16.0%
12	33 w.	0.402	0.021	5.2%	0.290	72.4%	0.090	22.4%
16	35 w.	0.224	0.015	6.7%	0.170	75.9%	0.040	17.9%
17	35 w.	0.373	0.036	9.7%	0.261	70.0%	0.075	20.1%
22	40 w.	0.642	0.042	6.5%	0.477	74.3%	0.124	19.3%
27	40 w.	0.411	0.033	7.1%	0.340	72.3%	0.096	20.4%
29	40 w.	0.935	0.062	6.6%	0.587	62.8%	0.281	30.1%
42	4½ m.	1.100	0.099	9.0%	0.735	66.8%	0.287	28.4%
43	5 m.	1.010	0.110	10.9%	0.730	72.3%	0.164	16.2%
46	14 m.	2.74	0.23	8.4%	1.87	68.2%	0.63	22.3%
55	3yrs9m.	3.59	0.47	13.1%	2.23	62.1%	0.86	24.0%

* Since the boundary between 'AF' and 'FC' is ill-defined, particularly where sections are tangential to this boundary, the accuracy of these figures is doubtful

Table 14

SUMMARY

Age Group	% of 'Disc Proper' due to NCNP	% of 'Disc Proper' due to 'A.F.'	% of 'Disc Proper' due to 'F.C.'
Fetuses (5)	7.1 $\pm$ 2.2	75.0 $\pm$ 5.5	17.5 $\pm$ 4.2
Newborn (3)	6.7 $\pm$ 0.3	69.7 $\pm$ 5.9	23.3 $\pm$ 5.9
Infants and Children (4)	10.4 $\pm$ 2.1	67.3 $\pm$ 4.1	22.7 $\pm$ 5.1

There is no statistically significant change in the % of the 'disc proper' due to 'F.C.' or to 'A.F.' The postnatal increase in the % of the 'disc proper' due to 'NCNP' is marginally significant (at the 5% level).

Table 15

Cross-sectional Areas of Intervertebral Disc and Notochordal Nucleus Pulposus Outlines (Text figs. 44, 46 and 48)

Age		NCNP AREA	DISC AREA	NP/DISC as %
1. CERVICAL	21w. (a.n.)	0.07 cm^2	2.0 cm^2	2.5%
	32w. (a.n.)	0.65 "	9.3 "	7.0%
	40w. (a.n.)	1.65 "	13.0 "	12.7%
	10m.	(*2.40 ")	22.3 "	-
	3yrs. 6m.	(*5.60 ")	29.0 "	-
(* In each case this figure represents the area of one notochordal nucleus pulposus only as no notochordal nucleus pulposus was present in the other cases in each group)				
2. THORACIC	21w. (a.n.)	0.30 cm^2	3.2 cm^2	9.4%
	32w. (a.n.)	1.65 "	13.5 "	12.2%
	40w. (a.n.)	4.9 "	24.2 "	20.2%
	7½m.	7.0 "	37.0 "	18.9%
	3yrs. 3m.	18.6 "	60.0 "	31.0%
	6yrs.	6.5 "	79.0 "	8.0%
3. LUMBAR	21w. (a.n.)	0.2 cm^2	3.6 cm^2	5.6%
	31w. (a.n.)	3.3 "	19.0 "	17.4%
	40w. (a.n.)	7.5 "	33.5 "	22.4%
	4m.	11.5 "	46.0 "	25.0%
	10m.	18.0 "	59.0 "	30.5%
	2yrs.	21.5 "	77.0 "	27.9%
	3yrs. 3m.	33.4 "	103.7 "	32.2%
	5yrs.	26.3 "	133.5 "	19.7%
	10yrs.	-	171.0 "	-

Text-fig. 42 (Table 15)

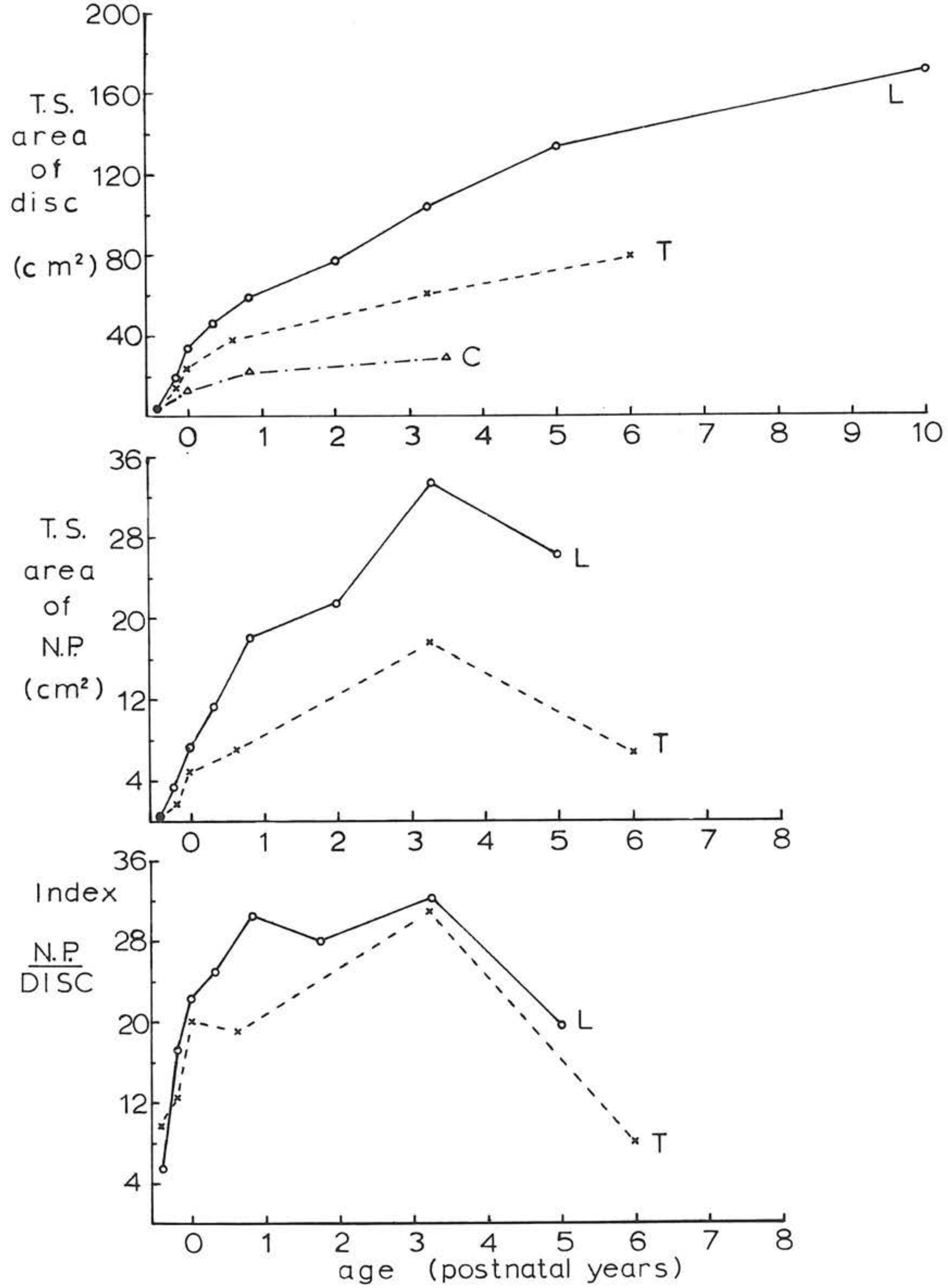
Cross-sectional area of discs and their nuclei pulposi measured by planimetry of horizontal outlines (Text-figs. 44, 46 & 48)

(a) Cross-sectional areas of the intervertebral discs, L 4-5 (L), T 8-9 (T) and C 5-6 (C)

(b) Cross-sectional areas of the notochordal nuclei pulposi of L 4-5 (L) and T 8-9 (T)

(c) $\frac{\text{Notochordal nucleus pulposus area}}{\text{intervertebral disc area}} \times 100$, i.e.

the percentage of the T.S. area of the disc due to the T.S. area of the notochordal nucleus pulposus for L 4-5 (L) and T 8-9 (T).



T.S. area of disc (cm²)
200
160
120
80
40
L
T
C
0 1 2 3 4 5 6 7 8 9 10
T.S. area of N.P. (cm²)
36
28
20
12
4
L
T
0 1 2 3 4 5 6 7 8
Index N.P./DISC
36
28
20
12
4
L
T
0 1 2 3 4 5 6 7 8
age (postnatal years)

Table 16

Volume and Surface Area of the Notochordal Nucleus Pulposus calculated from Average Linear Dimensions of NCNP

$V = 0.524 \times A \times B \times C$ ($A \simeq$ N.P. APD; $B \simeq$ N.P.LD; $C \simeq$ D.P.*)

$S = 3.142 \times \sqrt{AB} \times C$

Age	Number of Discs	Volume	Surface Area	V/S
THORACIC DISCS				
21 w.	3	0.76 mm^3	2.67 mm^2	0.28
32 w.	6	4.34 "	6.70 "	0.65
40 w.	3	19.78 "	18.40 "	1.08
$3\frac{1}{2}$ m.	1	36.97 "	26.11 "	1.42
5 m.	2	46.30 "	36.51 "	1.27
14 m.	2	39.70 "	33.02 "	1.20
2yrs 8m.	1	143.97 "	65.63 "	2.19
3yrs 4m.	1	214.58 "	110.06 "	1.95
3yrs 9m.	1	138.08 "	56.30 "	2.45
4yrs 9m.	1	66.97 "	51.81 "	1.29
LUMBAR DISCS				
21 w.	3	0.97 mm^3	3.19 mm^2	0.30
31 w.	8	16.32 "	17.52 "	0.93
40 w.	7	44.31 "	32.54 "	1.36
4 m.	5	96.11 "	56.89 "	1.69
10 m.	3	210.53 "	95.45 "	2.21
2 yrs.	4	254.02 "	109.31 "	2.32
3yrs 3m.	4	525.99 "	187.18 "	2.81
5 yrs.	2	585.83 "	239.41 "	2.45

(* N.B. The D.P. height is not an accurate indication of the N.P. height at 21 weeks, but it is a reasonably accurate guide thereafter.)

Table 17

Comparison of Lateral and Antero-Posterior Diameters of L4-5 Disc

X-ray Material

(uncorrected measurements)

Name	Age	A.P.D.	L.D.	INDEX APD/LD
McKenzie	Newborn	12.0	25.0	0.48
Walker	3 m.	11.0	24.0	0.46
Blair	4 m.	13.0	24.0	0.54
Brown	5 m.	14.0	25.0	0.56
McKay	7 m.	17.0	30.0	0.57
Douglas	8 m.	15.0	28.0	0.54
Findlay	8 m.	15.0	29.0	0.52
Redpath	9 m.	16.0	28.5	0.56
Jones	1 year	19.0	31.0	0.61
Patterson	1 yr 3m.	16.0	30.0	0.53
Gardiner	1 yr 4m.	17.0	27.5	0.62
McLennan	1 yr 8m.	16.0	33.5	0.48
Thomas	2yrs 4m.	16.0	30.0	0.53
Bagwell	2yrs10m.	21.0	36.0	0.58
Short	3 years	23.5	35.0	0.67
Walsh	3yrs 4m.	25.0	40.0	0.63
Buggy	3yrs 8m.	25.0	36.5	0.68
McFarlane	4 years	25.5	38.0	0.67
Fraser	4 years	22.0	35.0	0.63
Nelson	4yrs 6m.	27.5	43.0	0.64
Kerr	4yrs 7m.	25.0	40.0	0.63
Thompson	4 years	23.0	38.0	0.61
Thomson	5 years	25.0	35.0	0.71
Baillie	5 years	25.0	38.0	0.66
Erskine	5 years	26.0	40.0	0.65
Crighton	5 years	25.0	37.0	0.68
Castle	6 years	31.0	42.0	0.74
Bogle	6 years	32.0	47.5	0.67
Wyse	6 years	31.0	48.0	0.65
Miller	7 years	29.0	46.0	0.63
Weir	7 years	27.0	38.0	0.71
Griffin	7 years	29.0	44.0	0.66
Jappie	7 years	34.0	47.0	0.72
Nelson	7 years	29.0	46.0	0.63
Wilkie	7 years	27.0	40.0	0.68

Table 17 (contd.)

Name	Age	A.P.D.	L.D.	INDEX APD/LD
McFarlane	$8\frac{3}{4}$ yrs.	29.0	41.5	0.70
Forrest	9 yrs.	31.0	45.0	0.69
Tait	9 yrs.	36.0	50.0	0.72
Clark	10 yrs.	30.0	42.0	0.71
McDonald	10 yrs.	33.0	46.5	0.71
Anderson	10 yrs.	36.0	55.0	0.65
Heveron	11 yrs.	26.5	44.5	0.60
Tait	11 yrs.	40.0	57.0	0.70
Anderson	11 yrs.	30.5	45.0	0.68
Bruce	11 yrs.	35.0	54.0	0.65
Cosgrove	11 yrs.	36.0	52.5	0.69
Fowler	11 yrs.	33.5	49.0	0.68
Fegan	$11\frac{1}{2}$ yrs.	37.5	50.0	0.75
Wishart	$13\frac{1}{2}$ yrs.	37.0	46.0	0.80

Table 17

Means and Increments for 8 Age Groups

Age Range of Group	Mean Age	n =	Mean Disc Dimensions (mm) A.P.D.	S.D.	L.D.	S.D.	Mean APD/LD Index	S.D.	A.P.D. & L.D. Increments AP		L
N.B. - 6m.	3 m.	4	12.5	1.3	24.5	0.6	0.51	0.05			
7 m. - 1yr.	9 m.	5	16.4	1.7	29.3	1.2	0.56	0.03	3.9	$<$	4.8
1yr. 3m. - 2yr. 10m.	1yr. 10m.	5	17.2	2.2	31.4	3.3	0.55	0.05	0.8	$<$	2.1
3yr. - 4yr. 7m.	3yr. 11m.	8	24.6	1.7	38.2	2.8	0.64	0.02	7.4	$>$	6.8
5yr. - 6yr.	5yr. 5m.	7	27.9	3.3	41.1	5.0	0.68	0.03	3.3	$>$	2.9
7 years	7 years	6	29.2	2.6	43.5	3.7	0.67	0.04	1.3	$<$	2.4
8yr. 9m. - 10yr.	9yr. 6m.	6	32.5	3.0	46.7	5.1	0.70	0.03	3.3	$\simeq$	3.2
11yr. - 13½yr.	11yr. 5m.	8	34.5	4.0	49.8	4.5	0.69	0.06	2.0	$<$	3.1

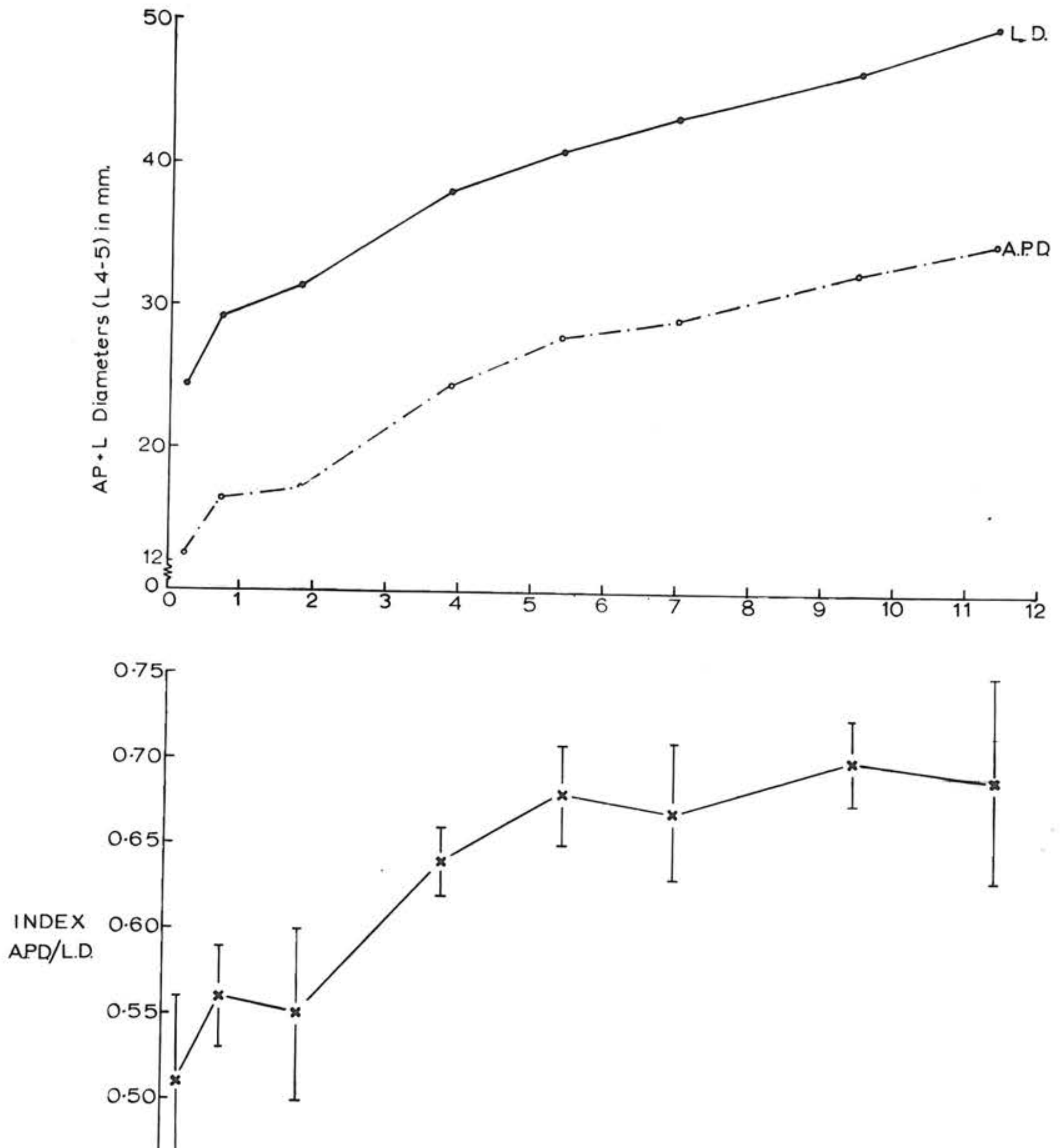
Text-fig. 43

Horizontal dimensions of L 4-5, measured on radiographs (Table 17)

(a) Mean anteroposterior and lateral diameters of L 4-5

(b) Index $\frac{\text{anteroposterior diameter}}{\text{lateral diameter}}$: means and standard deviations.

(cf. Text-fig. 38)



L. D.
A.P.D.
AP + L Diameters (L 4-5) in mm.
50
40
30
20
12
0
0 1 2 3 4 5 6 7 8 9 10 11 12
INDEX
APD/L.D.
0·75
0·70
0·65
0·60
0·55
0·50
0·45
0
0 1 2 3 4 5 6 7 8 9 10 11 12
AGE (years)

<u>Text-fig. 44</u> (i, ii, & iii)

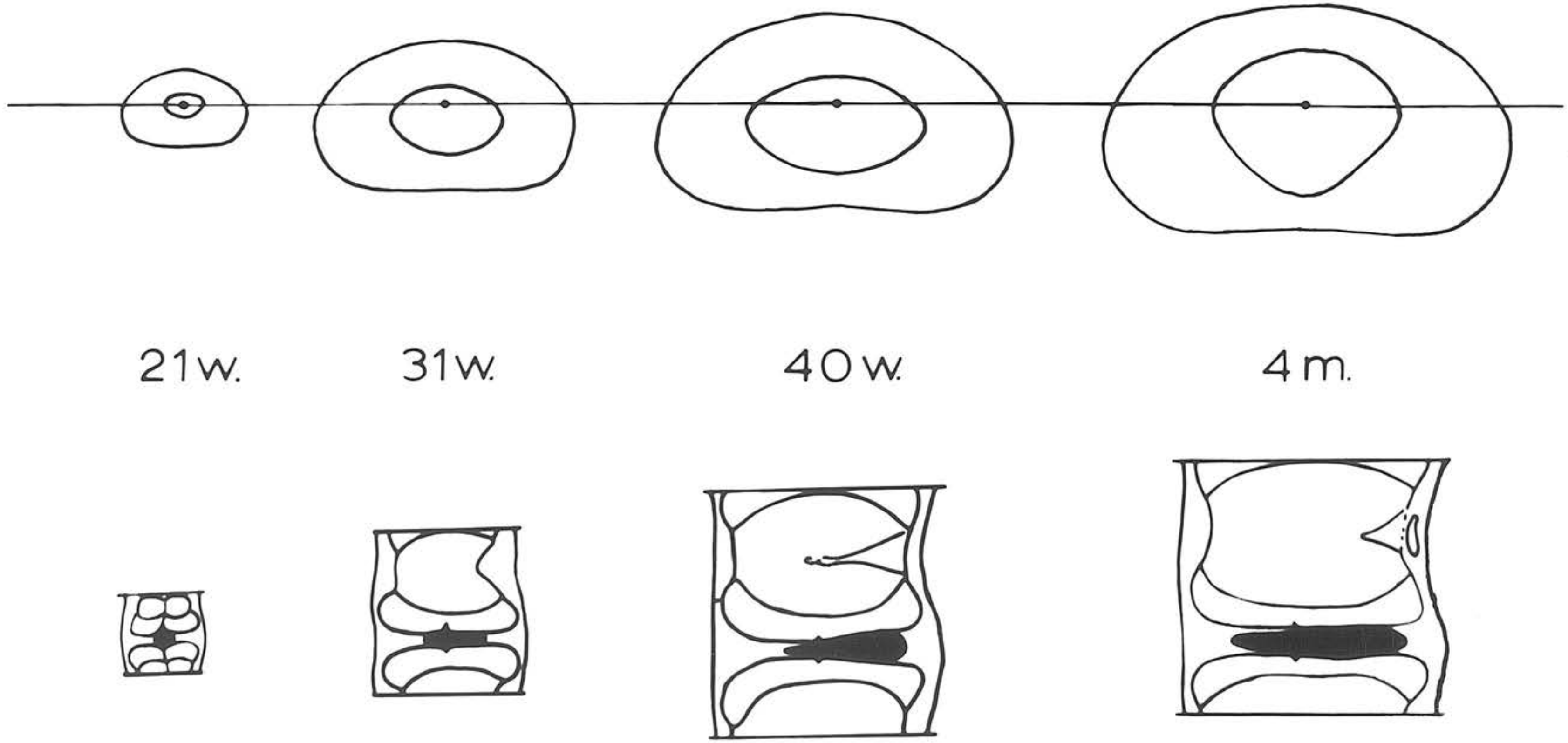
<u>Diagrammatic reconstructions of horizontal and median sagittal outlines of lumbar (L 4-5) discs (x 2.4), showing</u>

the intervertebral disc outline

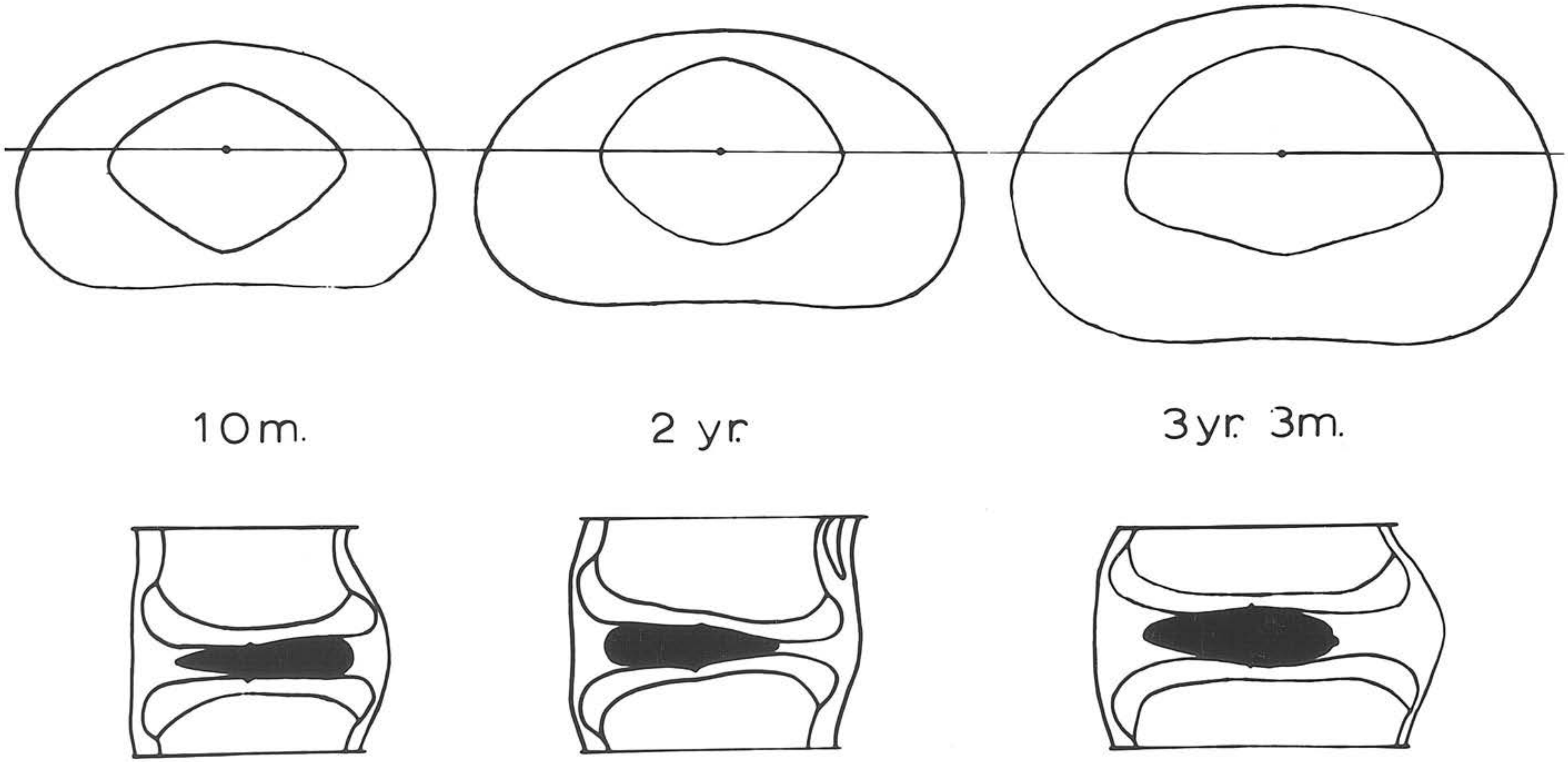
the notochordal nucleus pulposus position and outline

the position of the notochord or its remnants in the 'cartilage layers'

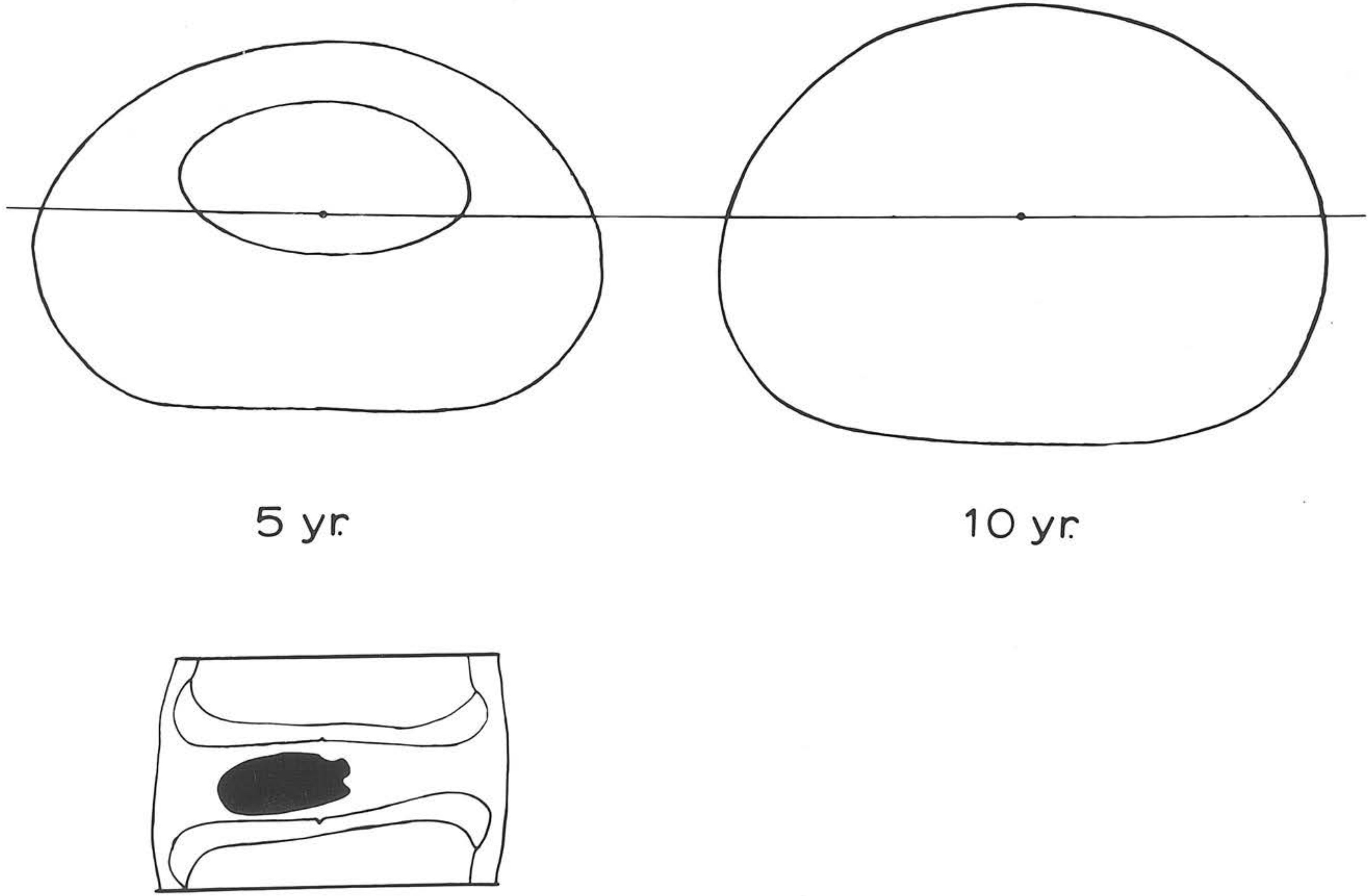
(for sagittal outlines, anterior is to the left)



44 (i) L 4-5



44 (ii) L 4-5



44 (iii) L 4-5

Text-fig. 45

Superimposition of horizontal outlines from Text-fig. 44 (L 4-5), 'centred' on the position of the notochord or its remnant, x 2.7

(a) changes in the size and position of the notochordal nucleus pulposus. (four stages only)

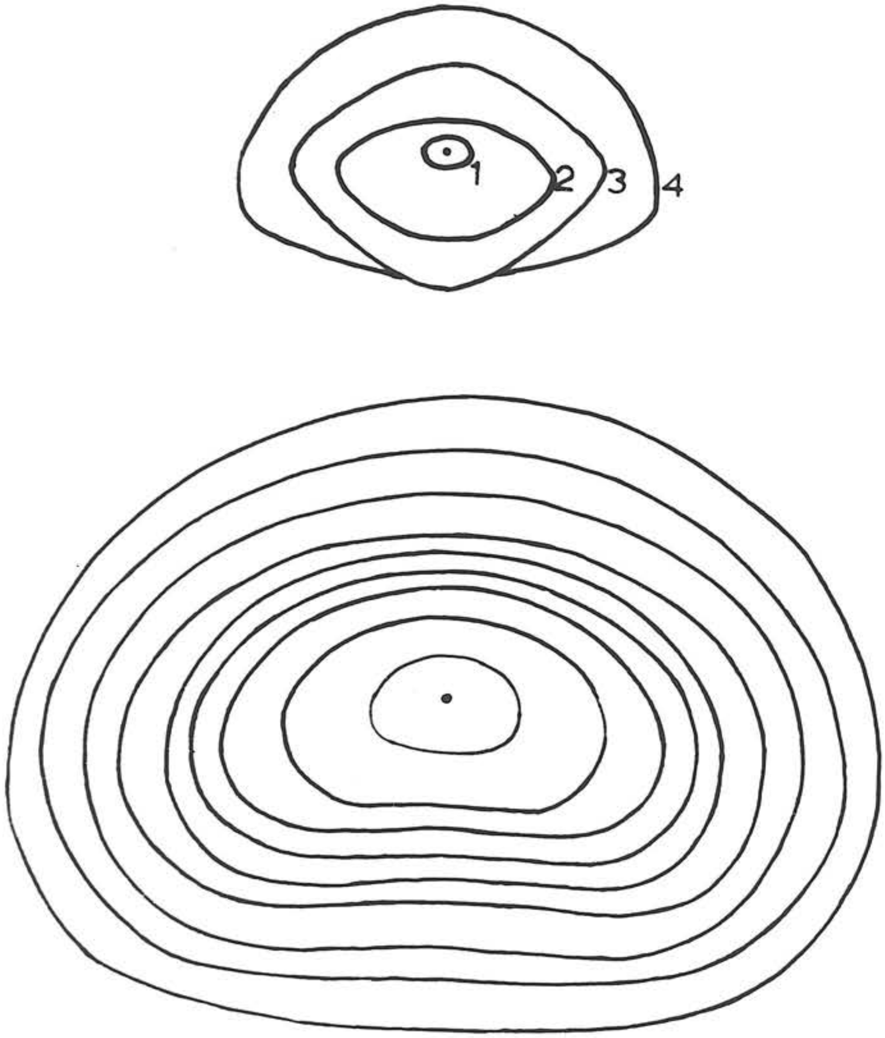
Initially, expansion is principally in posterior and lateral directions

Latterly, expansion is entirely in anterior & lateral directions

(b) Changes in size of the intervertebral disc.

Horizontal growth appears to be approximately equal in all directions.

1 21 weeks
2 40 weeks
3 10 months
4 3 years 3m.



L 4-5

Text-fig. 46 (i & ii)

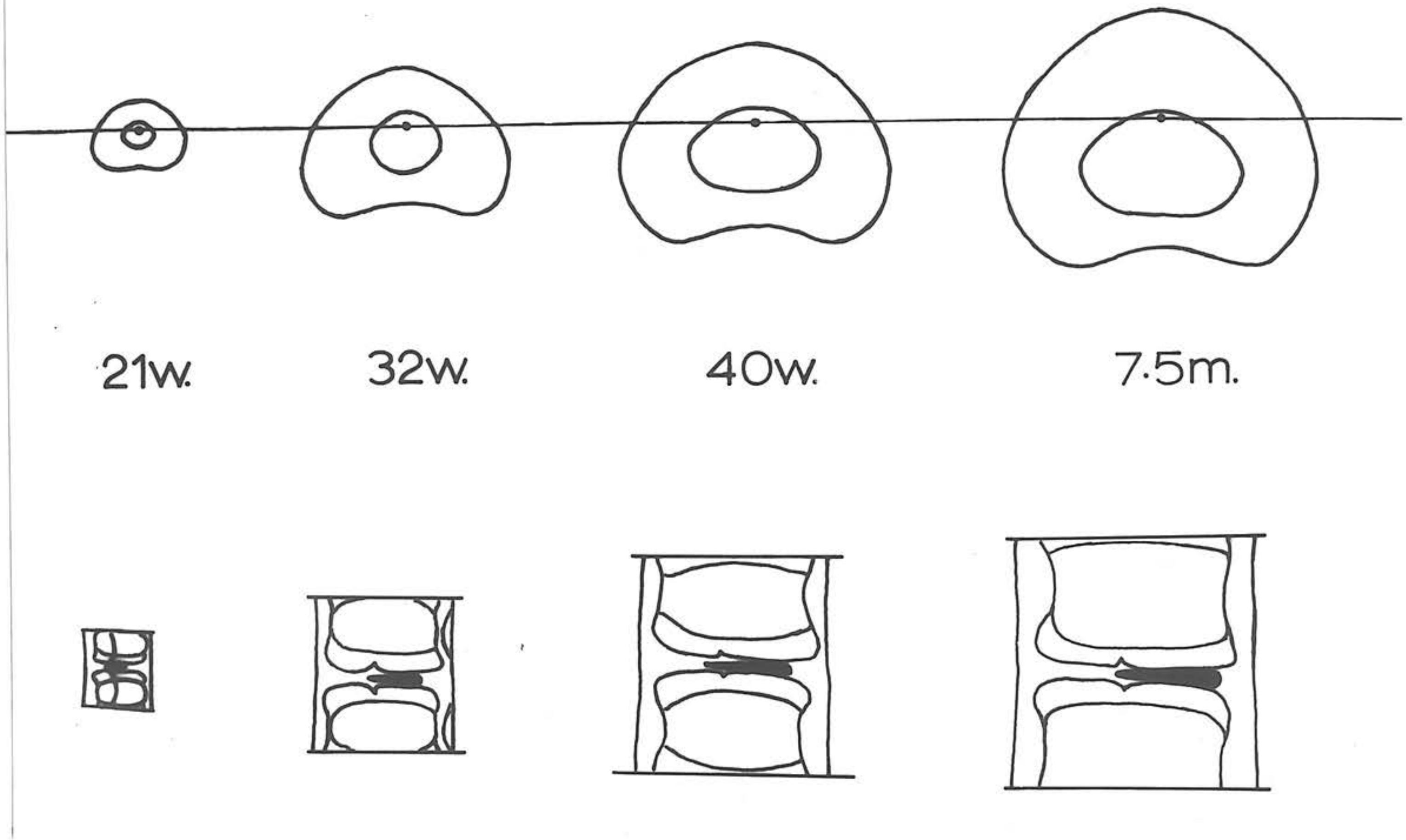
Diagrammatic reconstructions of horizontal and median sagittal outlines of thoracic (T 8-9) discs (x 2.4) showing:

the intervertebral disc outline

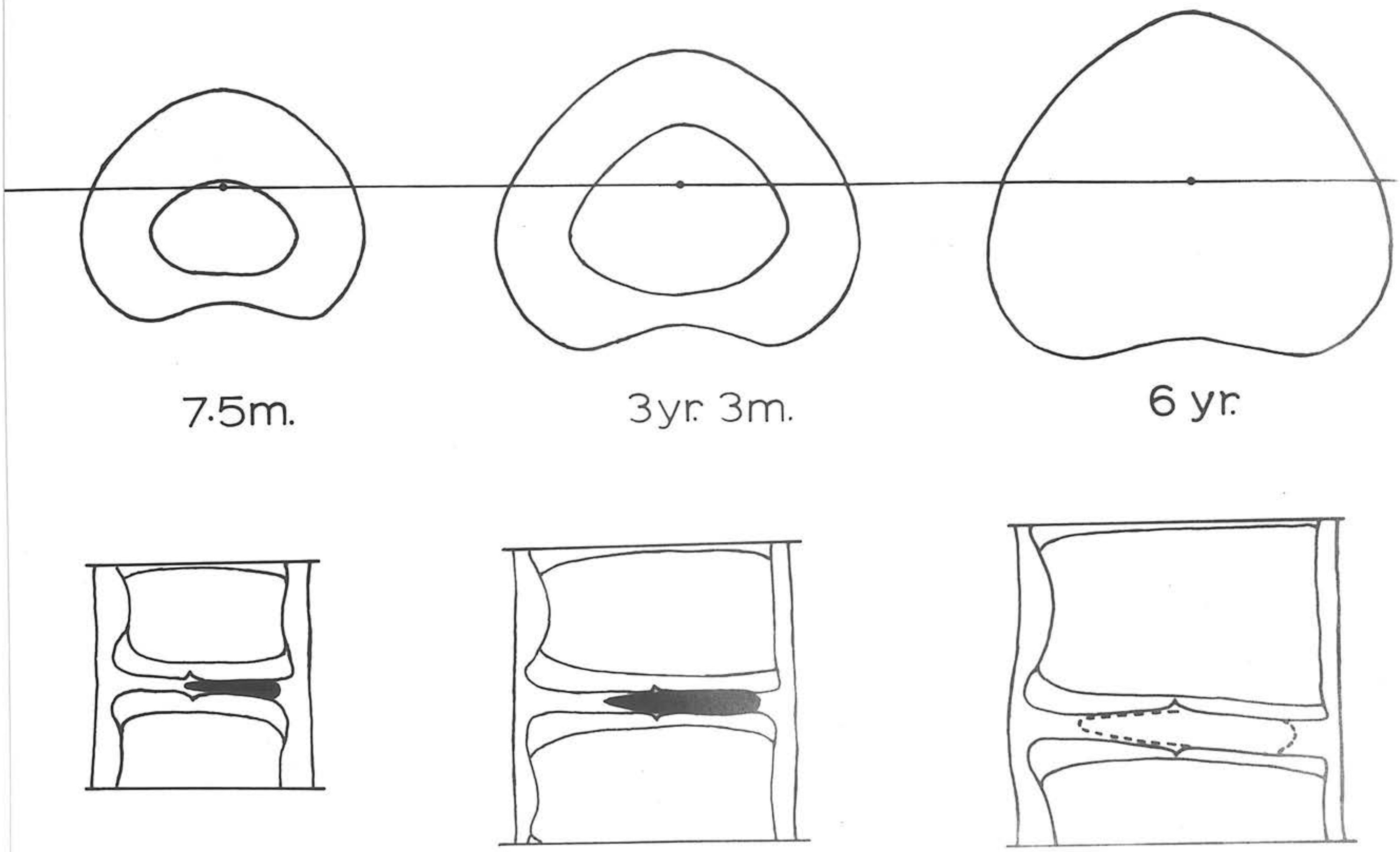
the notochordal nucleus pulposus position and outline

the position of the notochord or its remnant in the 'cartilage layers'

(for sagittal outlines, anterior is to the left)



46 (i) T 8–9



46 (ii) T 8-9

Text-fig. 47

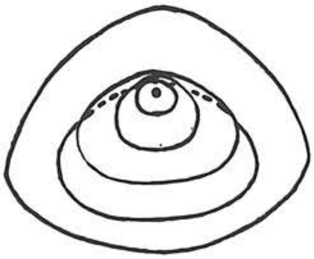
Superimposition of horizontal outlines from Text-fig. 46 (T 8-9), 'centred' on the position of the notochord, x 2.7

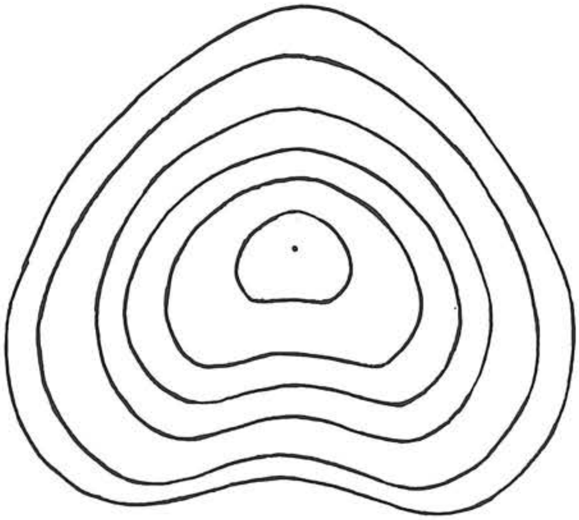
(a) outlines of successive stages of the notochordal nucleus pulposus (21 weeks to 6 years).

Expansion is almost entirely in posterior and lateral directions until after infancy.

(b) outlines of the intervertebral disc

(21weeks to 6 years)





T 8–9

Text-fig. 48 (i & ii)

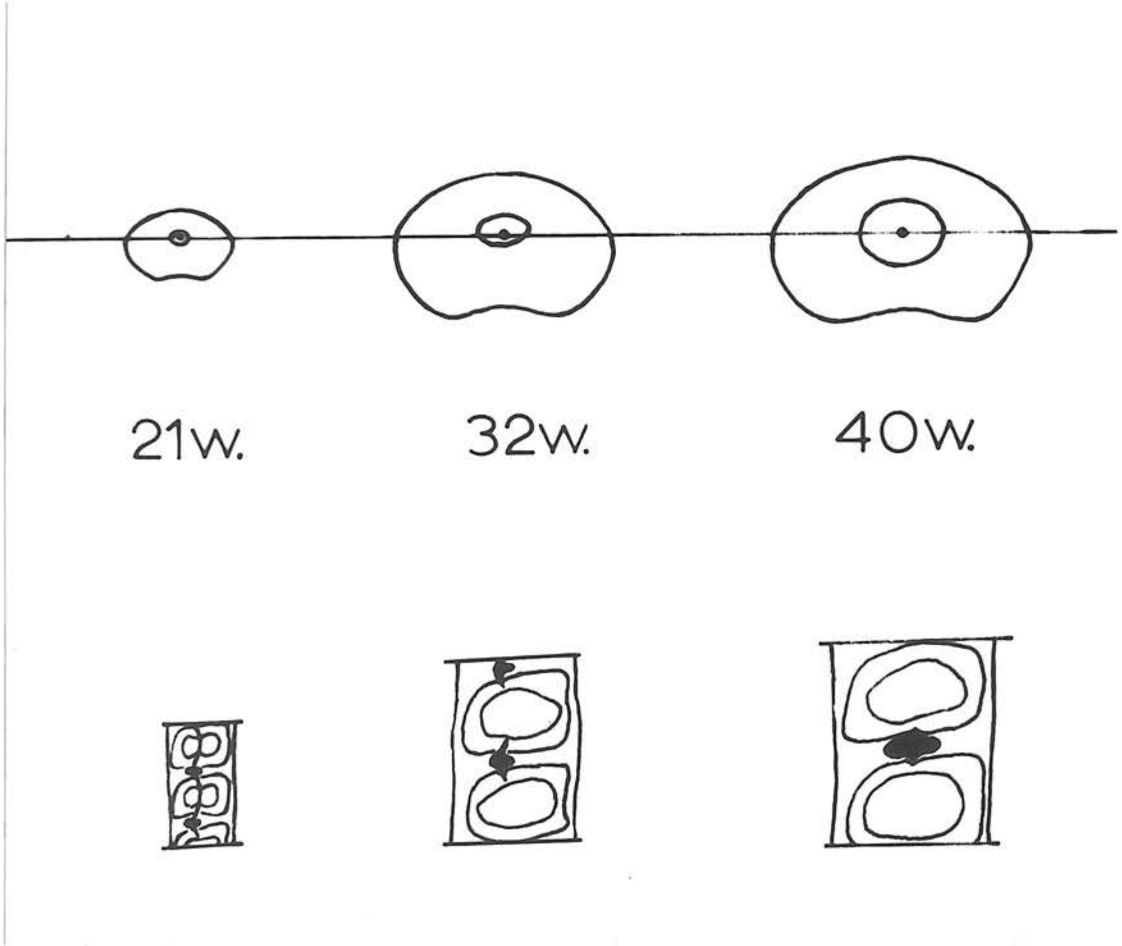
Diagrammatic reconstructions of horizontal and median sagittal outlines of cervical (C 5-6) discs (x 2.4) showing

the intervertebral disc outline

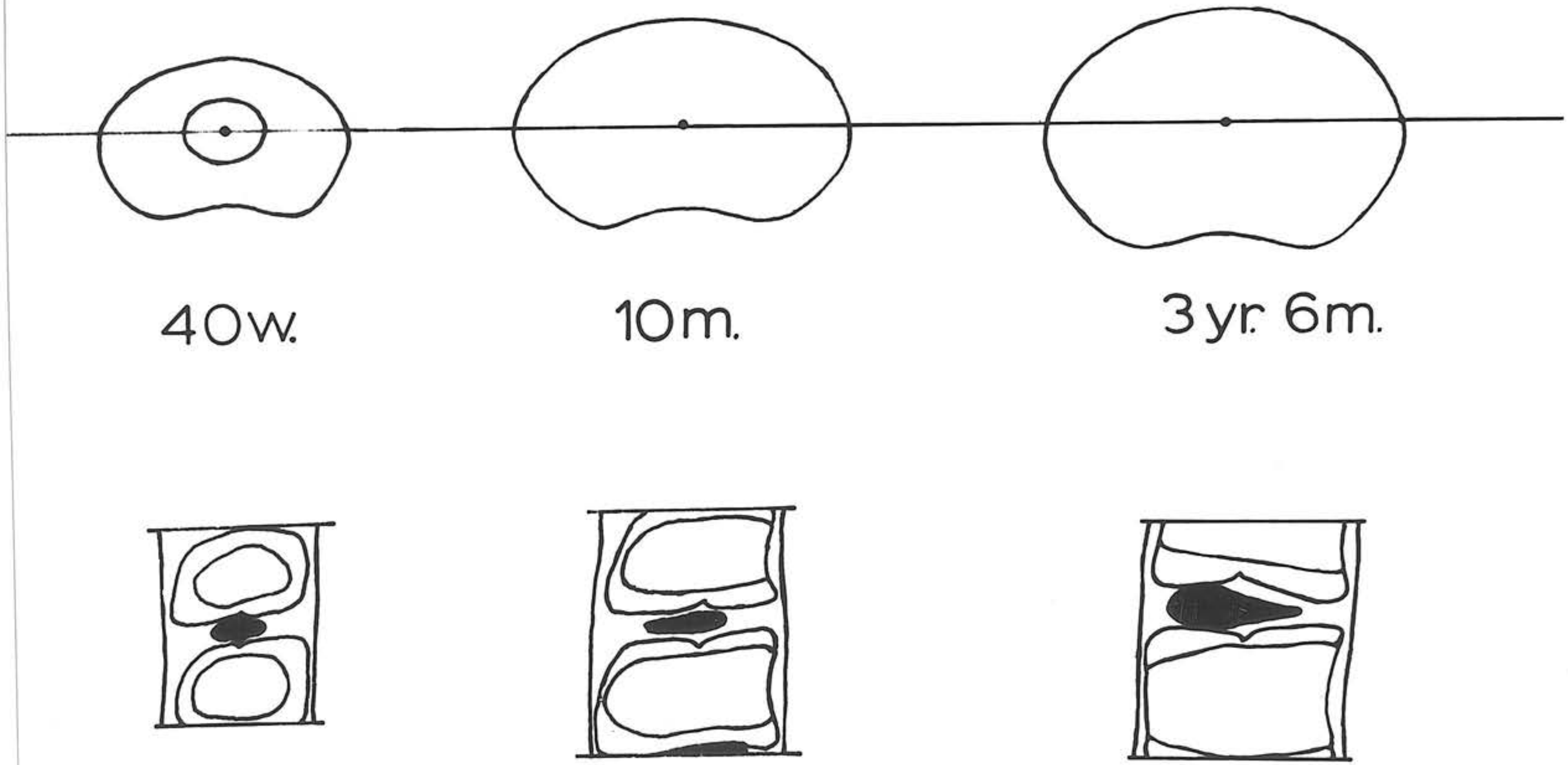
the notochordal nucleus pulposus position and outline

the position of the notochord or of its remnants in the 'cartilage layers'

(in sagittal outlines, anterior is to the left)



48 (i) C 5-6



48 (ii) C 5-6

Text-fig. 49

Horizontal growth in the cervical region.

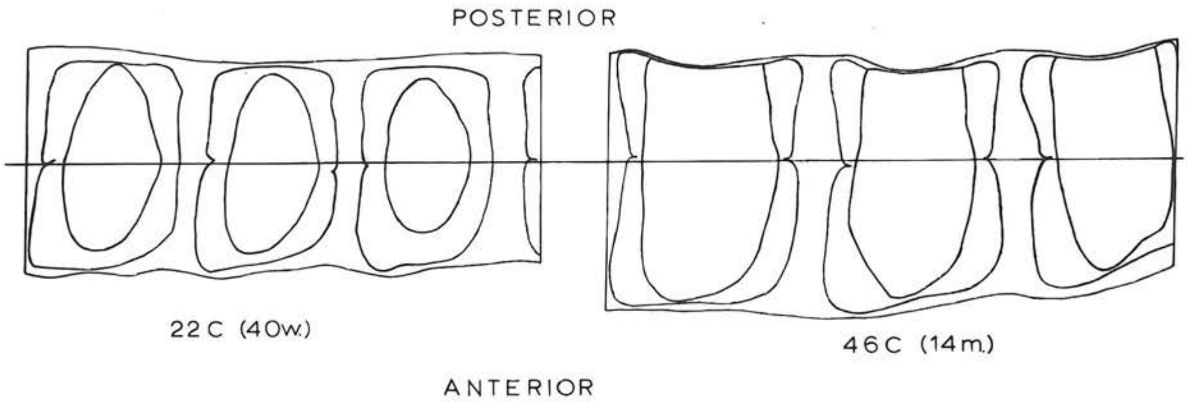
(a)

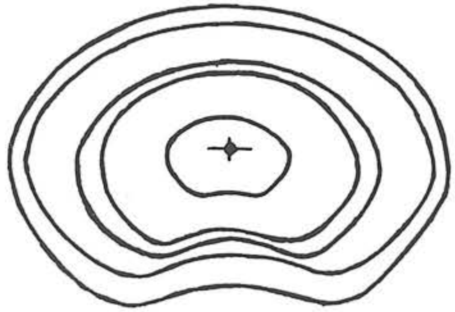
Tracings to the same scale (x 3.4) of median sagittal sections of a full term foetus and a fourteen month infant. The vertical line passes through the notochordal remnants in the 'cartilage layers'.

Growth appears to be in an anterior direction.

(b)

Superimposition of horizontal outlines from Text-fig. 48, centred on the notochord.
(from 21w. to 3yr. 6m.)
x 2.7





C 5-6

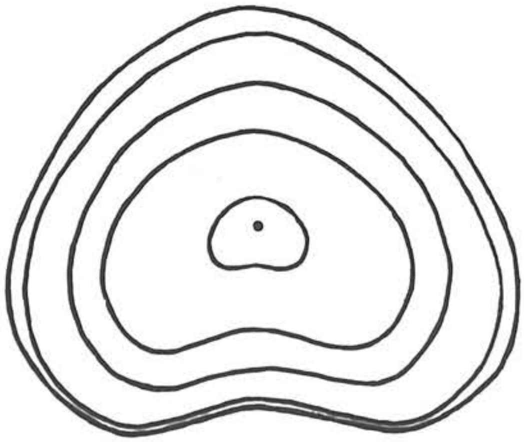
Text-fig. 50

Horizontal outlines of 'vertebral bodies', 'centred' on the position of the notochord (cartilage nodules).

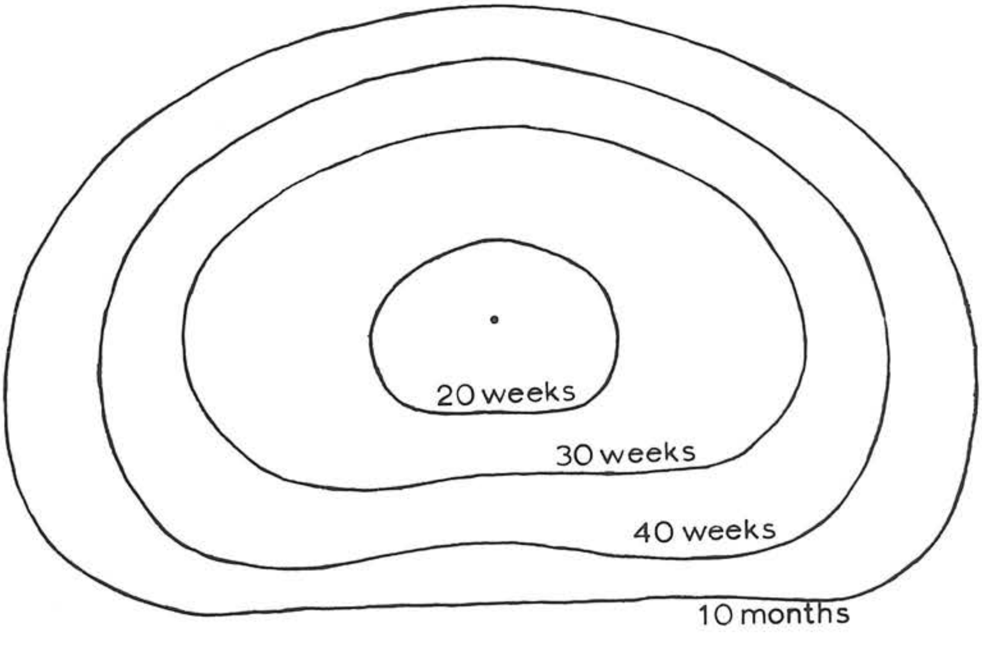
(a) Horizontal outlines of T 8 (x 2.5), at 21 weeks, 14 months, 3 years 4 months and 7 years 6 months. Latterly, growth is principally anterior and lateral in direction.

(b) Horizontal outlines of L 4 (x 5) from 20 weeks to 10 months.

HORIZONTAL GROWTH T8



Horizontal Growth L4



A DESCRIPTION OF THE INTERVERTEBRAL DISC DURING DEVELOPMENT

A. EARLY CHANGES IN THE NOTOCHORD AND INNER CELL ZONE (PERICHORDAL ZONE)

The notochord is still cylindrical in the cervical region of the seven week embryos (20 mm. CRL.) though it shows slight fusiform enlargement opposite the disc anlagen in lumbar and thoracic regions. In its cylindrical cervical portion the nuclear density is relatively greater in the disc portions than in the vertebral parts. Intercellular globules of clear mucoid material are numerous in all regions of the notochord. A few mitotic figures are seen.

At nine weeks (30 mm. CRL.) fusiform or rhomboidal swellings of the notochord are found in all discs and a fine strand of notochordal cells extends through each cartilaginous vertebral body. The 'foamy' appearance of the notochordal tissue which is characteristic of foetuses and infants is now well seen. This appearance is mainly due to intercellular globules of all sizes, but intracellular vacuoles are also seen. The perichordal zone has the appearance of embryonic hyaline cartilage. Numerous collagen bundles are seen in the outer third of the anulus fibrosus.

In thirteen, eighteen and twenty-two week foetuses the notochordal segments have enlarged and the notochordal cells are confined to the discs (except in the cervical region at 13 weeks where a few cells remain in the vertebra which is still cartilaginous). The notochordal cells appear to be stretched out into a 'chorda reticulum' by the accumulation of mucoid matrix between the cell strands. The cells themselves have a foamy appearance. Their nuclei are large, usually rounded, and contain a number of dense punctate chromatin granules. They are similar in appearance to the cells in the lumbar notochordal nucleus pulposus of a three year four month child. A mucoid streak traverses each vertebra in which ossification centres are developing (except in the thirteen week cervical region). At the margins of the notochordal segment, necrotic-looking portions of the surrounding tissue including collagen bundles can be seen mixing with the notochordal tissue.

In later foetuses (29 to 40 weeks) there is rapid increase in the size of the notochordal nucleus pulposus apparently with the incorporation of tissue from the inner cell zone. The inner cell zone no longer consists of hyaline cartilage but its numerous closely packed cells have elongated nuclei like fibroblasts and its matrix, which has mostly a clear hyaline appearance, contains a few randomly oriented collagen bundles. A much larger number of notochordal cells is present in the notochordal nuclei pulposi than at earlier stages, except in some cervical discs where the size of the notochordal segment is little greater than in younger foetuses. The mucoid matrix of the notochordal nuclei pulposi has also considerably increased, particularly in lumbar discs where part of the chorda reticulum is split up into separate clumps of notochordal cells in which from six up to sixty or more nuclei can be counted.

Text-fig. 51

(anterior is to the left in each case)

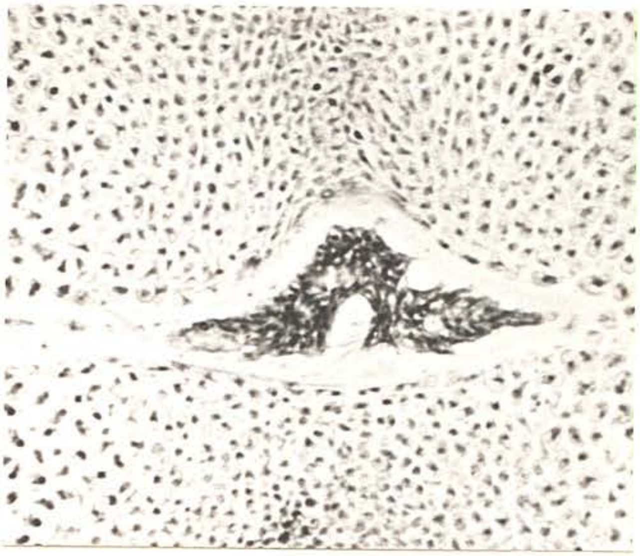
(a) Median sagittal sections of (left to right) lower cervical, mid-thoracic and lower lumbar discs from the 30 mm. embryo, E 5. x 40

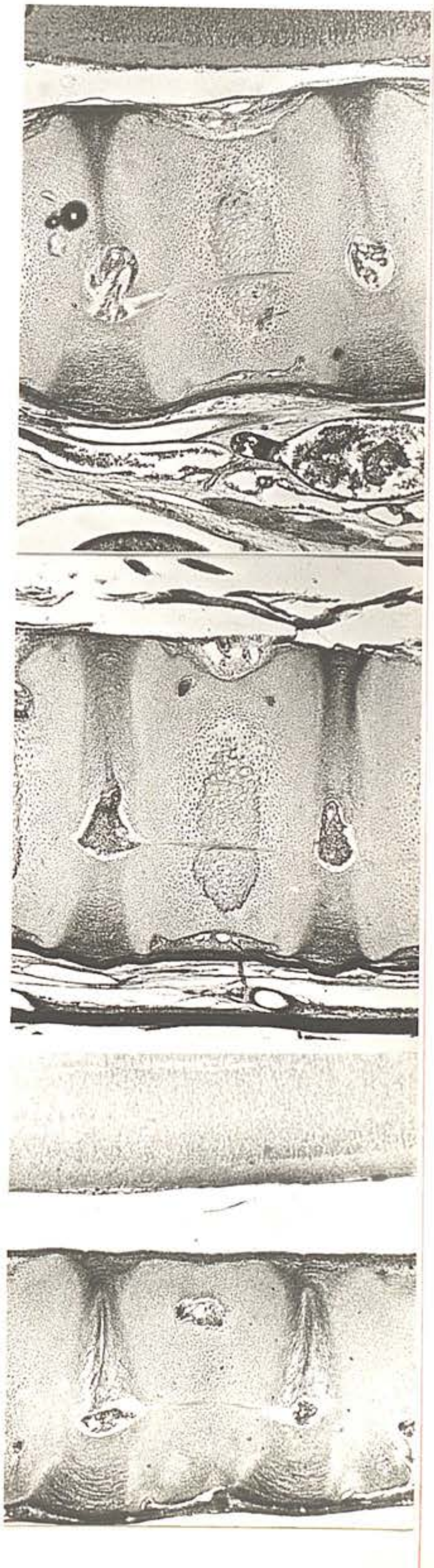
(b) a higher power view of the thoracic notochordal segment. Globules of mucoid material are apparent within the notochordal segment. x 140.

(c) Median sagittal sections of (left to right) lower cervical, mid-thoracic and lower lumbar discs and vertebrae from the 75 mm. embryo, E 6. x 20

Note the curved mucoid streak in cervical and lumbar regions.

Primary centres of ossification are seen in thoracic and lumbar vertebral bodies.



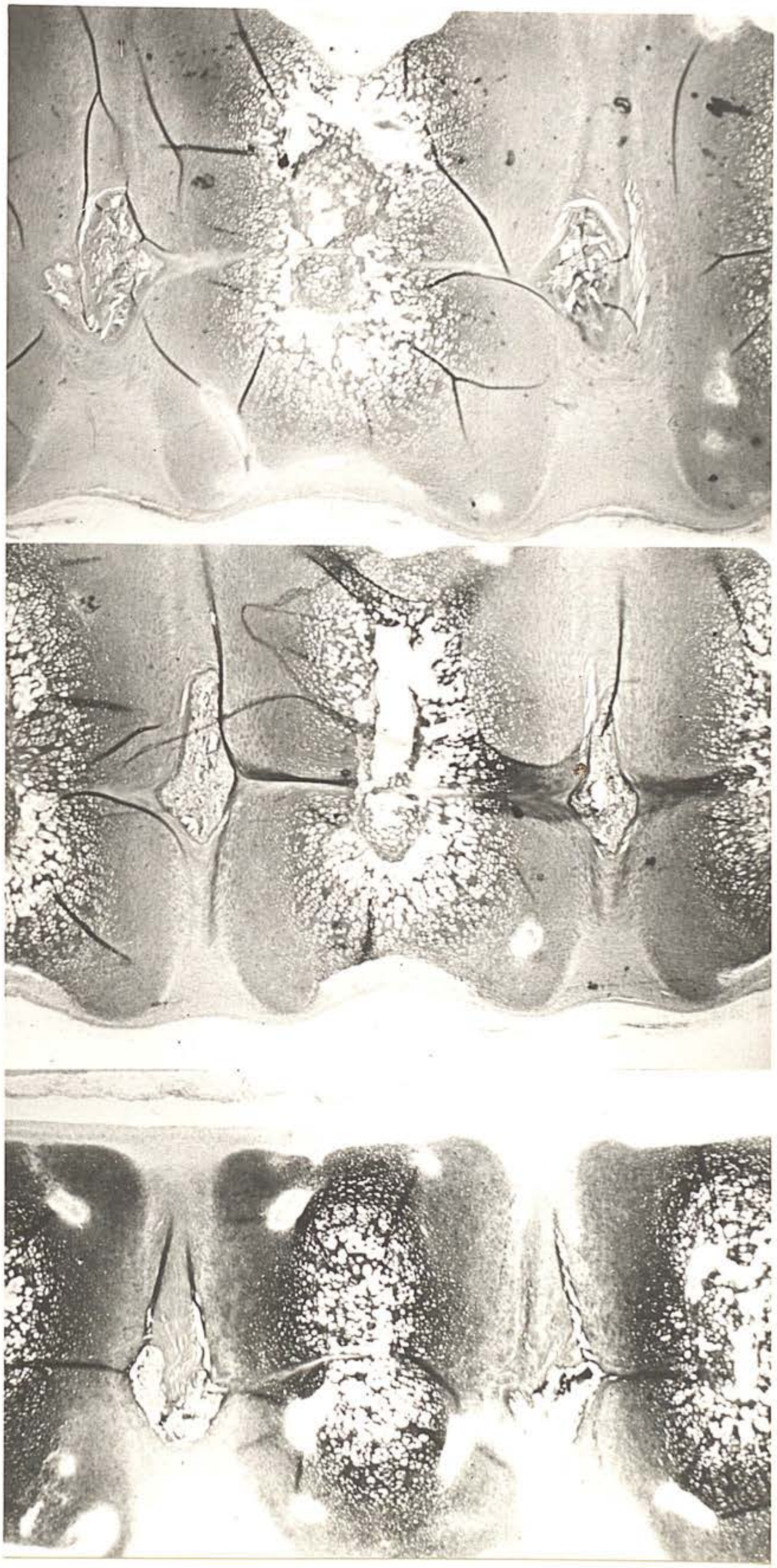


Text-fig. 52

(anterior is to the left in each case)

Median sagittal sections of (left to right) lower cervical, mid-thoracic and lower lumbar discs and vertebrae from the 18 week foetus, case no. 1 (115 mm. C.R.L.). x 20

The thoracic and lumbar notochordal segments are considerably larger than in Text-fig. 51 (c). The mucoid streak is still visible, and close to it, the spread of ossification appears to be retarded.



Text-fig. 53

Notochordal Cells.

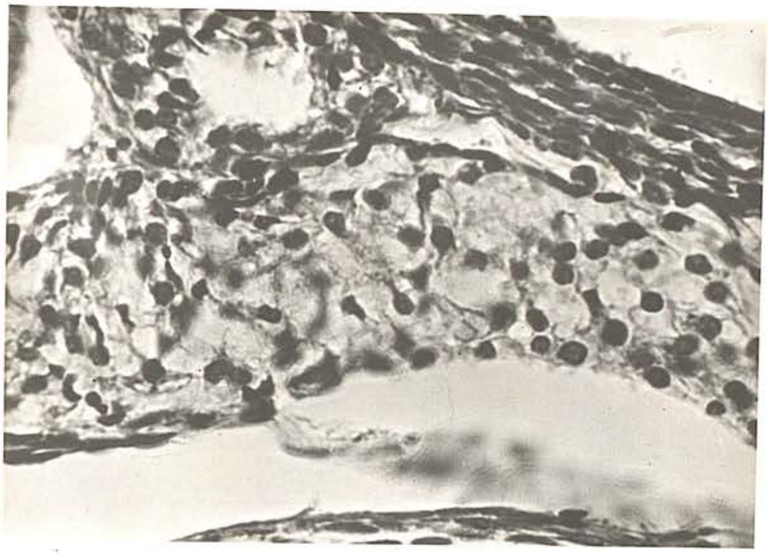
(a) Notochordal cells in the 28 mm. embryo E 4, showing intercellular globules of clear mucoid material.

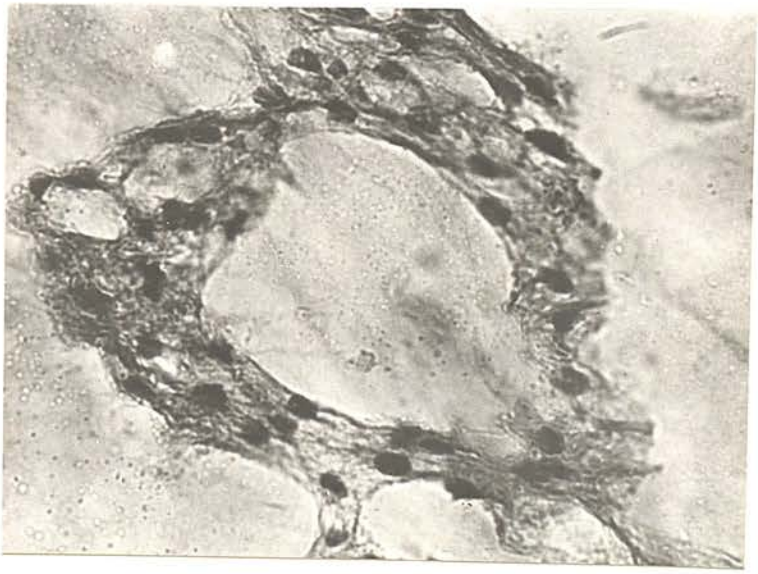
The tissue shown lies rostral to the odontoid process.

10 micron wax embedded section, x 500.

(b) Notochordal cells in a four month infant, (case no. 41 L), forming part of a 'chorda reticulum' embedded in plentiful clear mucoid matrix.

50 micron (L.V.N.) section, x 600.



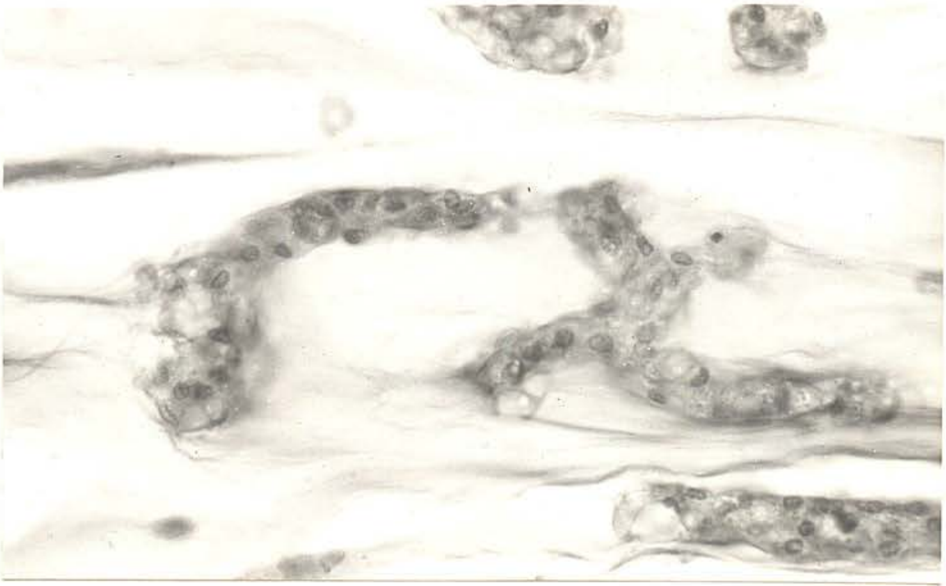


Text-fig. 54

Notochordal Tissue in Foetuses.

(a) The central part of the nucleus pulposus in a sagittal section from a 40 week foetus (case no. 25, L 4-5), showing clumps and strands of notochordal cells in a plentiful mucoid matrix.
150 micron section, x 100.

(b) Notochordal cell clumps in the lumbar nucleus pulposus of a 35 week foetus (case no. 17).
150 micron section, x 480.



B. PERSISTENT NOTOCHORDAL FEATURES IN CARTILAGE PLATES AND BONY VERTEBRAL BODIES

1. Persistence of the Mucoid Streak in Cartilage Plates

The mucoid streak is no longer found in normal centra after the 22 week stage, but parts of it persist in the cartilage plates throughout prenatal life, infancy, and childhood. At the junction of the notochordal segment with the mucoid streak in early foetuses there is a funnel-shaped extension of the notochordal segment projecting into the cartilage plate towards the developing centrum. This persists in older foetuses and is continuous with a clear cell free area extending deeper into the cartilage plates, similar in appearance to the mucoid streak (Text-fig. 55). In infants and children this 'diverticulum' into the cartilage plates persists caudal and cephalic to the notochordal nucleus as a 'dimple' in the surface of the cartilage plate adjoining the 'disc proper' even though it may no longer lie opposite and is not continuous with the notochordal tissue of the nucleus pulposus (Text-fig. 79). It is found in all three regions of the vertebral column and in most of the cases in the present series. In many of the infants and children in the present series the clear cell free area, reminiscent of the mucoid streak, also extends from the apex of the 'diverticulum' or 'dimple' into the 'cartilage layer' towards the ossification front of the centrum.

2. Persistence of Cartilage Nodules or Cylindrical Tracks in Vertebral Centra

Small areas of calcified cartilage persist around the mucoid streak in the thoracic and lumbar vertebrae of 18 and 22 week foetuses. Vertical extension of ossification in the centra seems to be retarded in the region of the mucoid streak where 'bays' of cartilage persist giving the centrum a bilobed appearance in median sagittal sections. In the region of the centre of the thoracic and lumbar centra of a number of older foetuses, infants, and children small isolated areas of calcified cartilage persist (Text-figs 56,57 and Table 18). These cartilage nodules have an appearance similar to the cartilage described around the mucoid streak of early foetuses. In thoracic and lumbar vertebrae of a few full term foetuses and infants (cases Nos. 8, 25, 32, 37 and 45, see Table 18(c) and Text-fig. 58) a cylindrical track of cartilage persists from each cartilage plate towards the centre of the centrum, apparently along the line of the former mucoid streak. These cylinders of cartilage appear to consist mainly of fibrocartilage with cells oriented vertically parallel to the cylindrical track. In two cases, a core of acellular fibrillar material passes through the centre of the cylinder. One of these cylinders of cartilage, (case No. 37T) widens near the centre of the centrum and contains a small triangular area of tissue similar in appearance to the notochordal tissue in a full term foetal nucleus pulposus (Text-fig. 59). These appearances are reported in an earlier publication (Taylor, 1972). The shape and position of the wider parts of the cylindrical tracks near the centre of vertebral centra (e.g. case 37, fig. 58) resemble the shape and position of the cartilage nodules described in cases 4, 6, 7, 16 etc. (Text-figs. 56 & 57 but none of the latter contain any notochordal tissue.

TABLE 18 (a)

PERSISTENCE OF CARTILAGE NODULES OR CYLINDRICAL TRACKS IN VERTEBRAL CENTRA

(15 cases)

Serial No.	Age	Vertebrae Involved	Type of Notochordal Remnant
4	29w.	T & L	cartilage nodules
6	30w.	T & L	" "
7	30w.	T -	" "
8	30w.	L (no T available)	cylindrical track
16	35w.	T -	cartilage nodules
19	36w.	L (no T available)	" "
21	40w.	T & L	" "
25	40w.	T & L	cylindrical tracks
32	40w.	L (no T available)	" "
37	1 month	T & L	" "
40	$3\frac{1}{2}$ "	T -	cartilage nodules
45	10 "	- L	cylindrical track
46	14 "	T -	cartilage nodules
54	3yr.4m.	T -	" "
59	7yr.6m.	T -	" "

TABLE 18 (b)

INCIDENCE OF PERSISTENCE OF CARTILAGE NODULES AND CYLINDERS IN VERTEBRAL CENTRA

	Foetuses	Newborn	Infants	Children
Age Range	25-38w.	38w-1m.	1m-12m.	1-10 yrs.
Serial Nos. of Cases	13-19	20-37	38-45	46-60
No. in Group	17	18	8	15
Cases of 'Persistent Cylindrical Track'	1	3	1	0
Cases of 'Persistent Cartilage Nodules'	5	1	1	3
No. of Cases with Cartilage 'Remnants'	6(35%)	4(22%)	2(25%)	3(20%)

TABLE 18 (c)

HISTOLOGICAL NATURE OF CYLINDRICAL TRACKS

Case No.	Age	Vertebrae Involved	Nature of Track
8	30w.	L 4	Fibrocartilage(partly interrupted by ossification)
25	40w.	T8 & 9 & L5	Mainly fibrocartilage with a fibrillar acellular core
32	"	L 4	Fibro cartilage
37	1 month	T7, 8 & 9 and L 4	Mainly fibrocartilage with a fibrillar acellular core and with notochordal tissue near the centre of T 9
45	10 months	L 4	Fibrocartilage (partly interrupted by ossification

The notochordal remnants in vertebral bodies are found in 15 out of 58 cases over 22 weeks gestation. They are present in 11 out of 22 such thoracic blocks, and 8 out of 58 available lumbar blocks.

C. REGIONAL VARIATION IN THE POSITION OF THE NOTOCHORD AND IN THE COURSE OF THE NOTOCHORD OR ITS REMNANTS THROUGH THE VERTEBRAL COLUMN (TEXT-FIGS. 60 - 62).

The course of the notochord in 7 - 9 week (20 - 30mm.) embryos is straight and its position is slightly anterior of the centre of vertebrae and discs; rather more anterior of the centre in the thoracic region than in the cervical and lumbar regions.

In a thirteen week foetus the cervical notochordal segments are small and anteriorly situated; the thoracic segments are also anteriorly situated but beginning to extend posteriorly, while the lumbar segments are globular and centrally situated. The mucoid streak is convex posteriorly in the cervical and lumbar vertebrae but straight in middle and lower thoracic vertebrae. This situation persists with little change in 18 and 22 week foetuses.

In cervical discs of older foetuses and newborn infants the notochordal nucleus pulposus may remain rudimentary or develop into a flat central elipse. In the thoracic region it assumes a posterior position, disconnected from notochordal remnants in the cartilage plates; and it becomes a large posteriorly situated wedge-shaped mass, also disconnected from the notochordal remnants in the cartilage plates, in lumbar discs. No cartilage nodules are found in cervical vertebrae, but lines joining notochordal remnants in the vertebrae and cartilage plates are directed dorsally at the centre of lumbar and thoracic centra (Text-fig. 62), except for case No. 37 where the corresponding lines are directed anteriorly. The line joining such notochordal remnants is almost straight in the thoracic vertebral column of children.

TABLE 19

Age	Cervical Region	Thoracic Region	Lumbar Region
7- 9 w.	Straight	Straight	Straight
18-22 w.	Dorsal curve in vertebra	"	Dorsal curve in vertebra
30-40 w.	-	Dorsally directed at centre of centrum	Dorsally directed at centre of centrum

In TEXT-FIGS. Nos. 55 - 102, all illustrations are of thick sections (150 or 200 microns), stained by haematoxylin and light green, unless it is stated otherwise in the Text-fig. legend.

Text-fig. 55

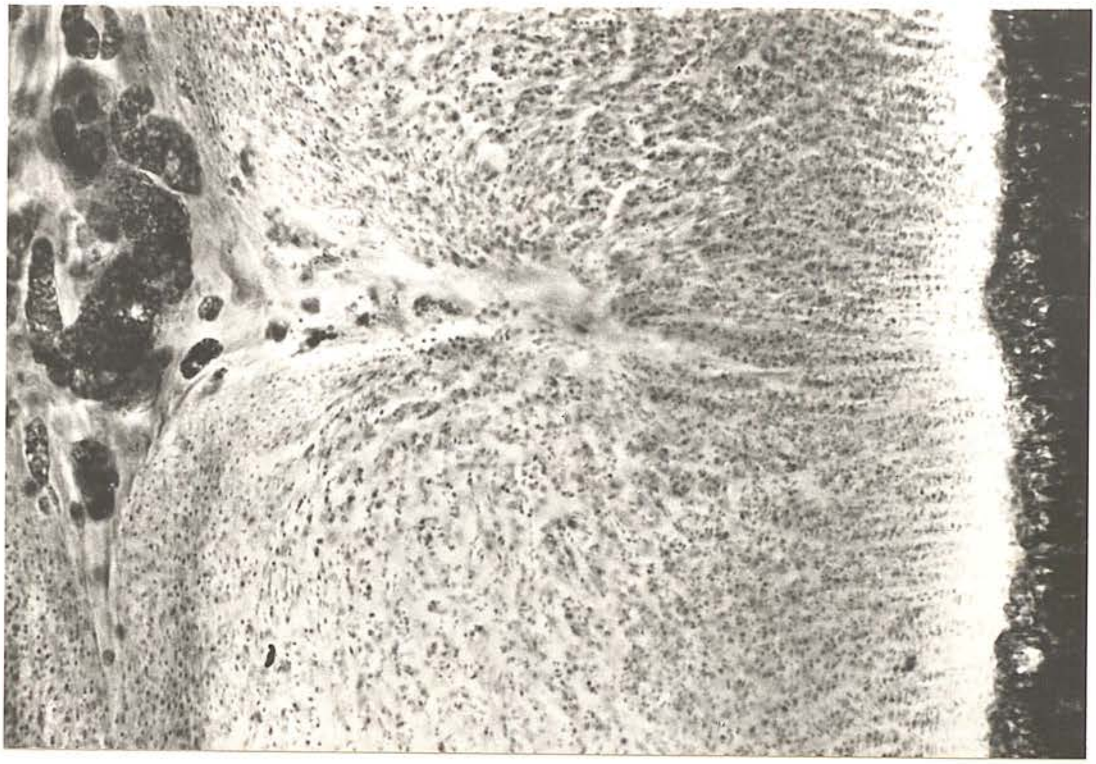
Persistence of the 'mucoid streak' in the 'cartilage layers'

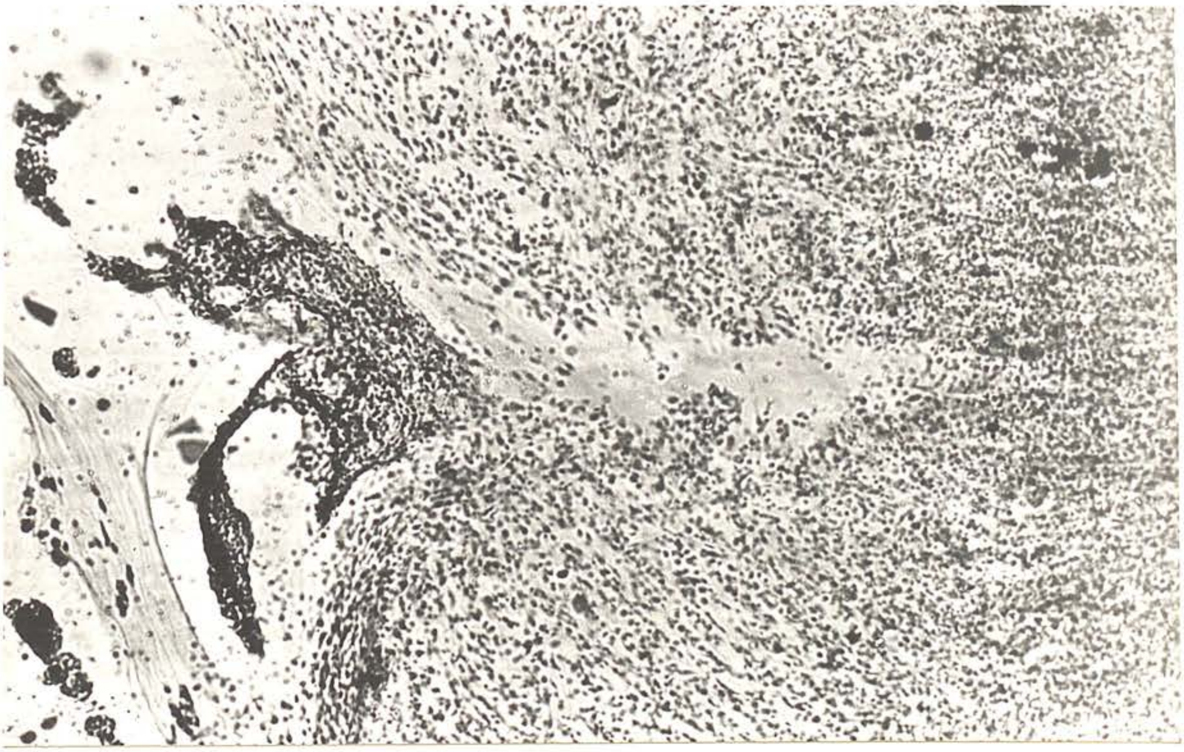
(cf. Text-fig. 10)

(a) Median sagittal section of the nucleus pulposus and cartilage plate (L 4-5) from a 36 week foetus (case no. 19) x 100.

(b) Coronal section of the nucleus pulposus and cartilage plate (L 4-5) from a 30 week foetus (case no. 6) x 80.

Note the funnel shaped depression from the nucleus pulposus intó the 'cartilage layer' and the clear cell free zone extending through the 'cartilage layer' in each case.





Text-fig. 56

Persistent Cartilage Nodules in Vertebral Bodies.

(a) Median sagittal section of a thoracic vertebral body from a 30 week foetus (case no. 7).

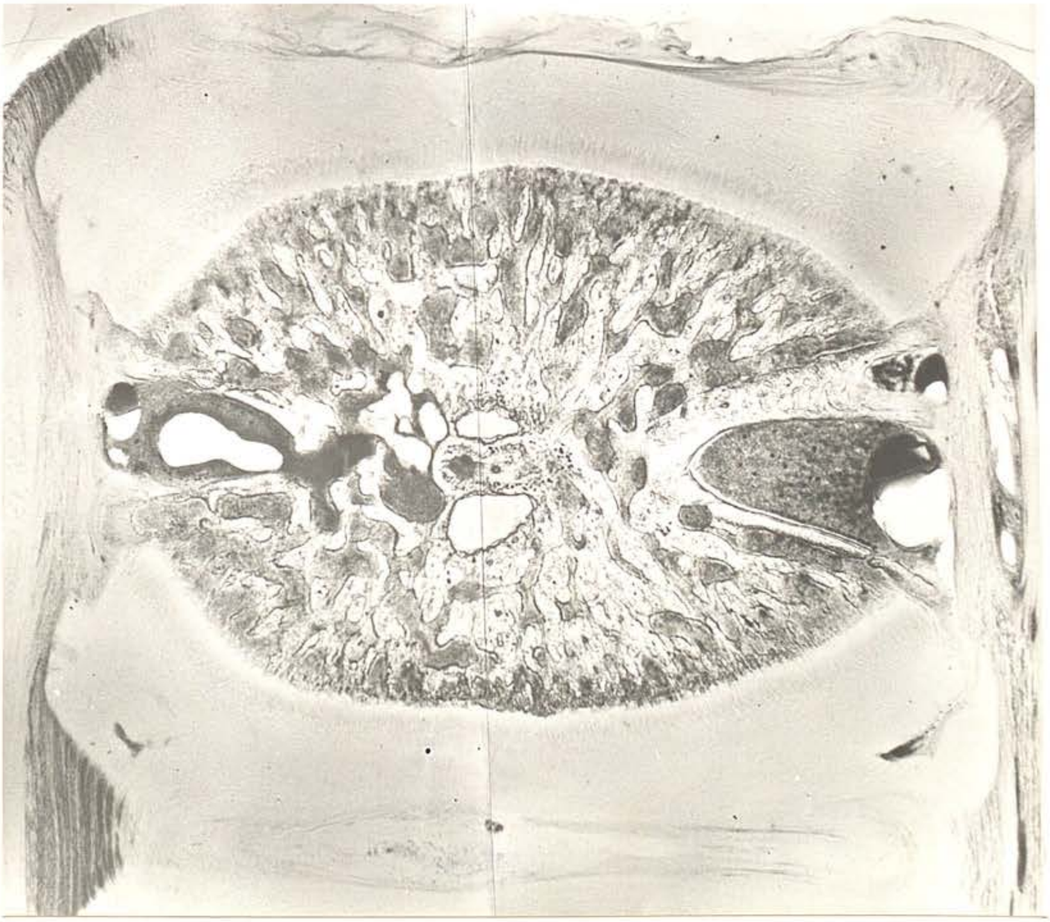
x 12

(anterior is to the right)

(b) Median sagittal section of a thoracic vertebral body from a 35 week foetus (case no. 16).

x 15

(anterior is to the left)



Text-fig. 57

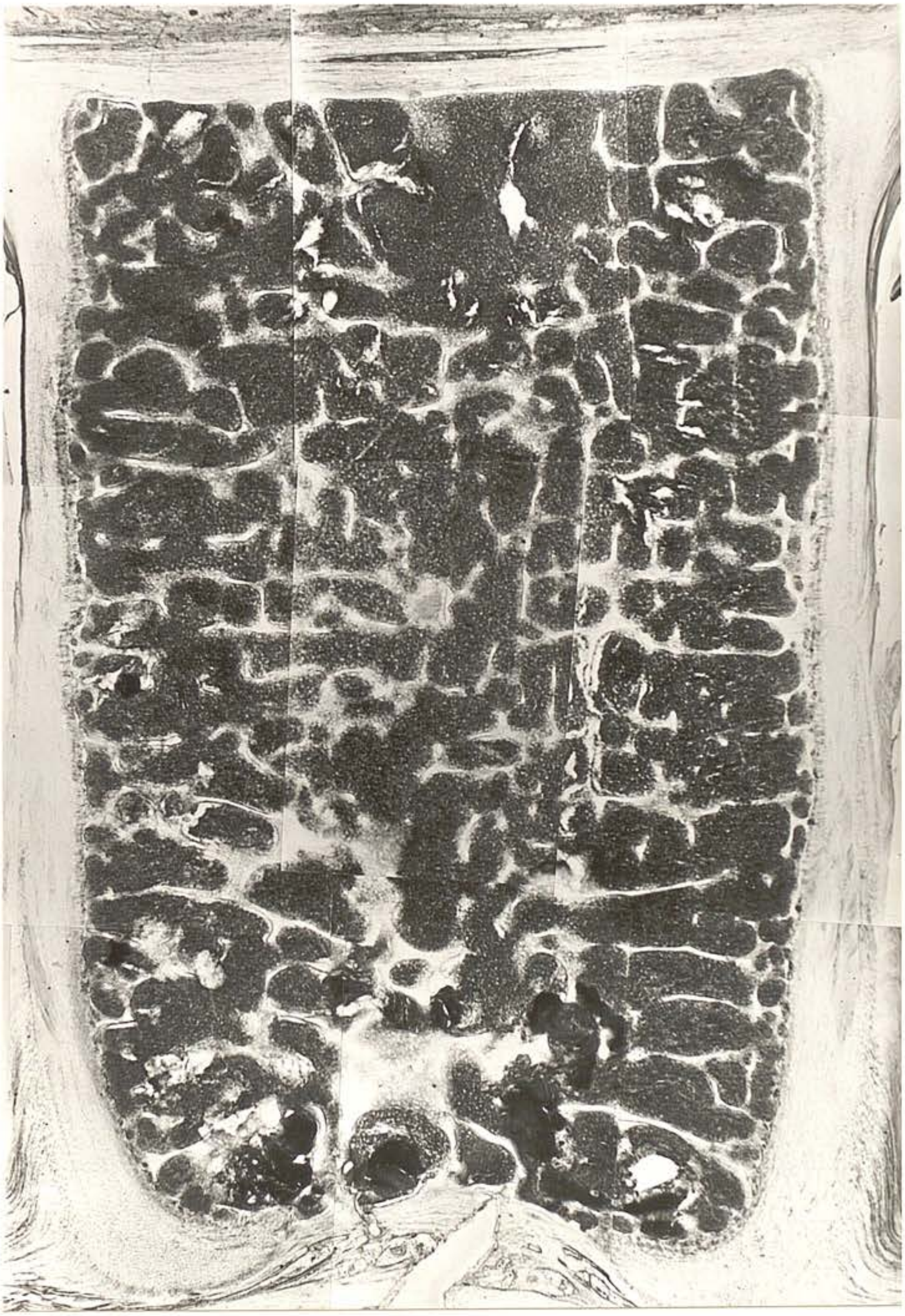
Persistent Cartilage Nodule in a Vertebral Body.

Median sagittal section of a thoracic vertebral body from a seven and a half year old child (case no. 59).

x 8.

A single cartilage nodule is visible at the centre of the centrum.

(anterior is to the left)



Text-fig. 58

Persistent Cartilaginous Cylindrical Tracks in Vertebral Bodies, with Deformities of the Vertebral Bodies.

Median sagittal section (montage) of thoracic vertebral bodies and discs from a one month infant (case no. 37), x 10 showing cylindrical cartilaginous tracks in T 7, T 8 and T 9. These tracks are bent obliquely forwards towards the centres of the vertebral centra. In this situation the cartilage cylinders are wider than elsewhere, and resemble the cartilage nodules illustrated in Text-fig. 56.
Near the centre of T 7 notochordal tissue is found within a cartilage cylinder (see Text-fig. 59 (a)).

Vertebral centra show 'nipple like' deformities projecting into the discs around the cartilage cylinders, and associated with a bilocular notochordal nucleus pulposus in T 7-8.

These abnormal vertebral centra may be compared with the normal shape of the vertebral centrum at this age, illustrated in Text-fig. 89 b.

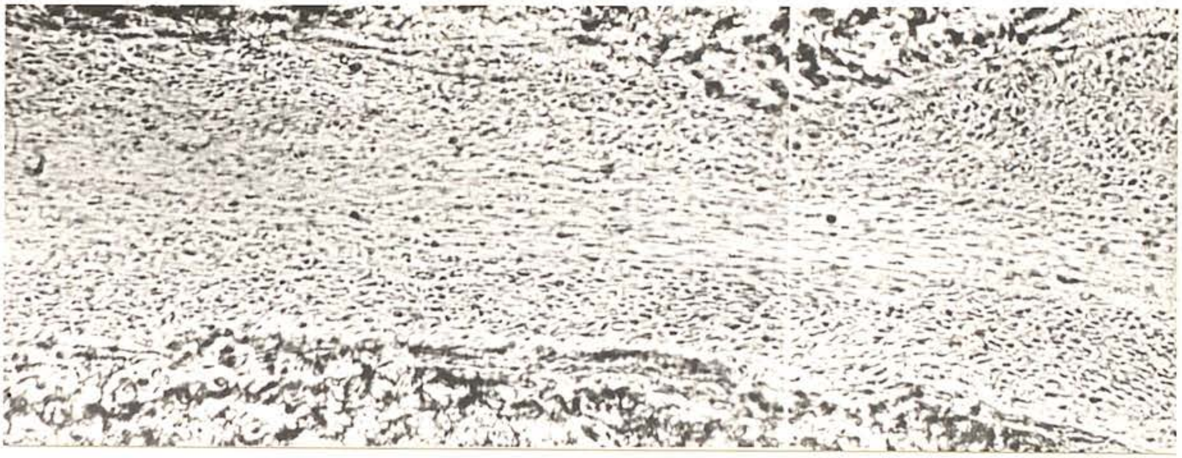
(anterior is to the left)

Text-fig. 59

Higher power views of parts of the Cartilage Cylinder in the lower part of T 7 (Text-fig. 58).

(a) Notochordal tissue, similar in appearance to the nearby notochordal nucleus pulposus, from the wider part of the cartilage cylinder near the centre of the centrum of T 7.
200 micron section, x 150.

(b) The narrow part of the cartilage cylinder in T 7, approaching the cartilage plate of the disc, T 7-8.
x 100.



Text-fig. 60 (i - iv)

The Relative Sizes and Positions of the Notochordal Nucleus Pulposus in Different Regions of the Vertebral Column.

(anterior is to the left)

Tracings of median sagittal sections of cervical, thoracic and lumbar regions of the vertebral column, ranging from a 30 mm. embryo (8 weeks) to a 3 year 9 month child.
(In each print, the tracings are from the same individual, traced to the same scale, but the scale differs in different prints).

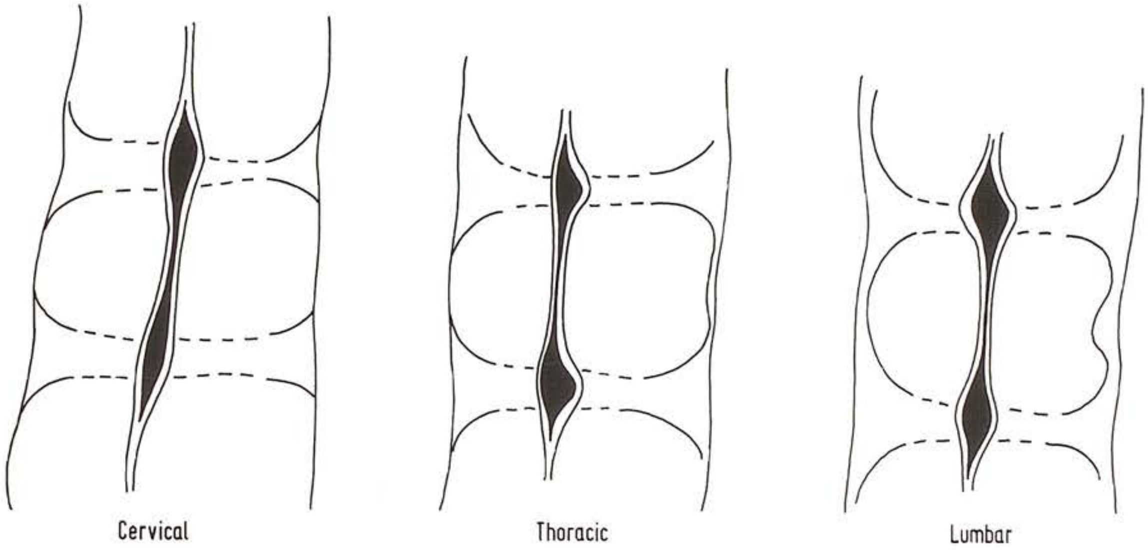
Black = notochordal tissue

White = hyaline cartilage

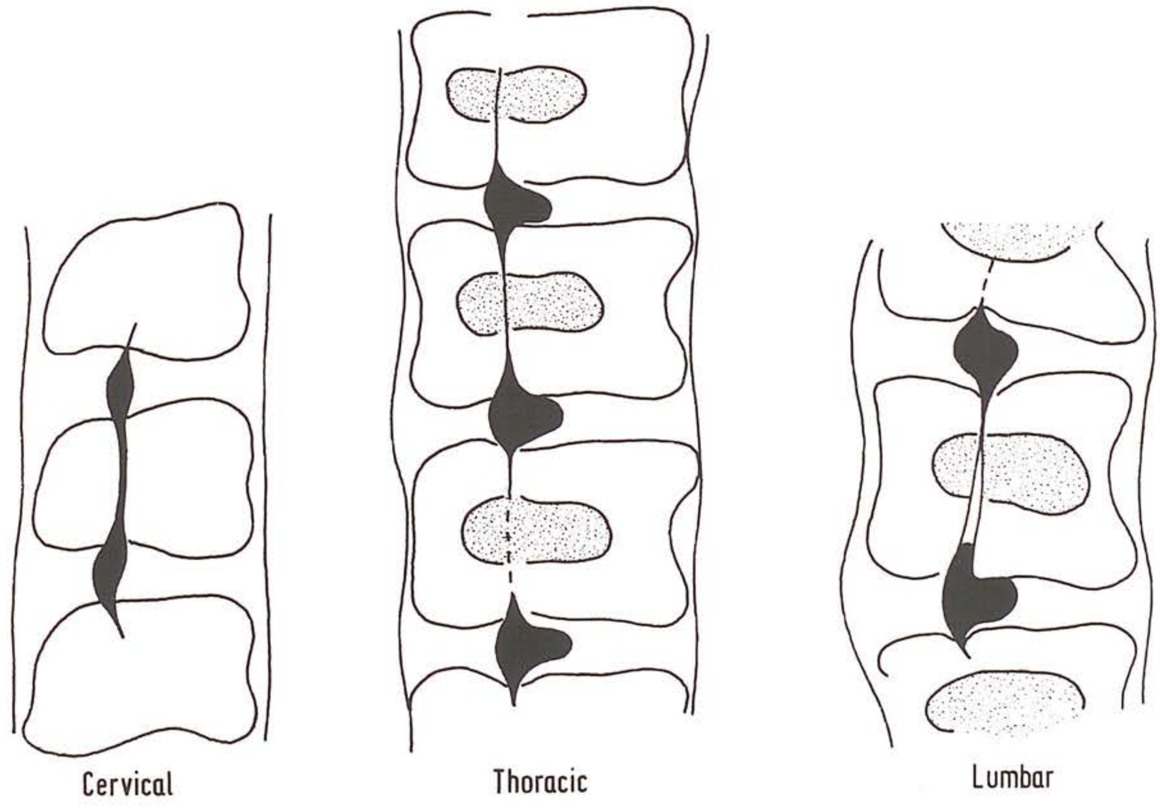
Stippled areas = bone of developing centra.

Note the delayed development of cervical notochordal segments prenatally (Text-fig 60 (ii)). Cervical notochordal nucleus pulposus development is widely variable postnatally.

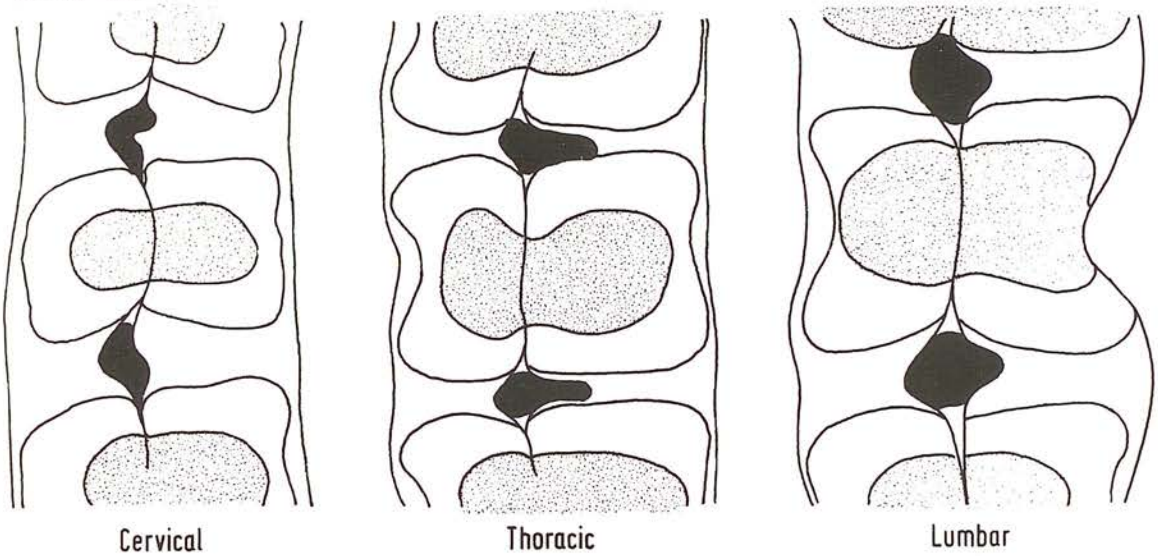
30mm CRL



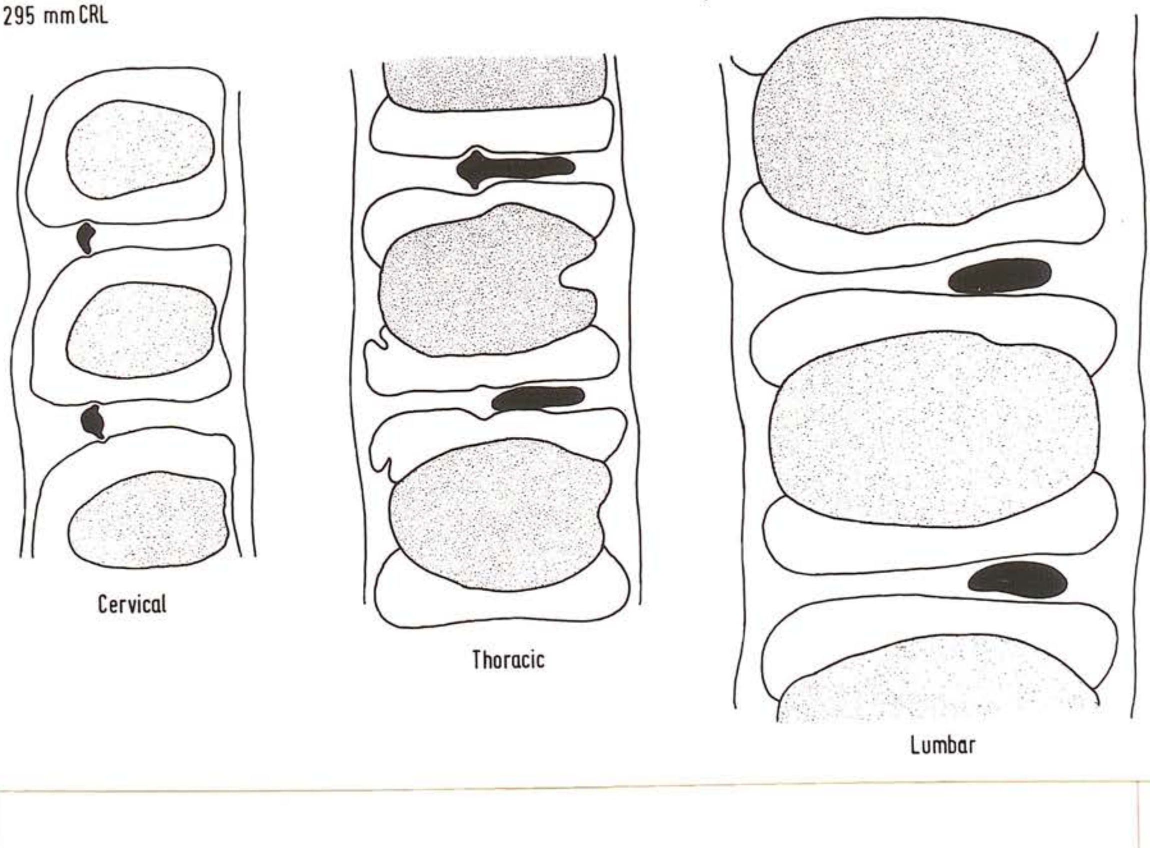
75mm CRL

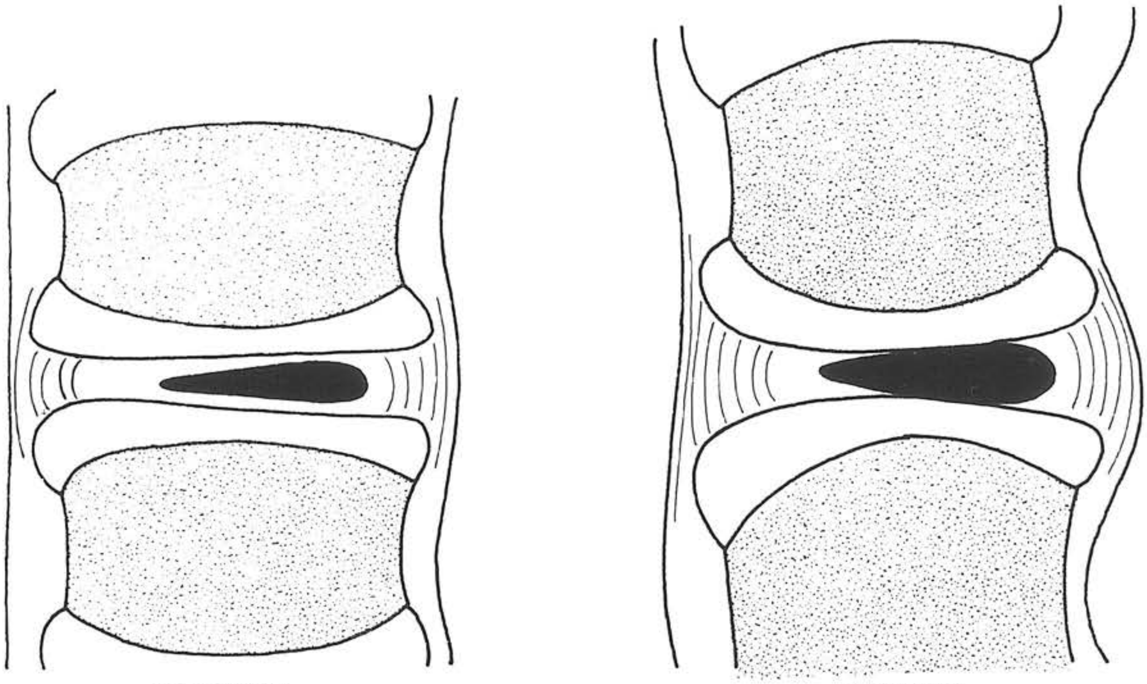


115mm CRL



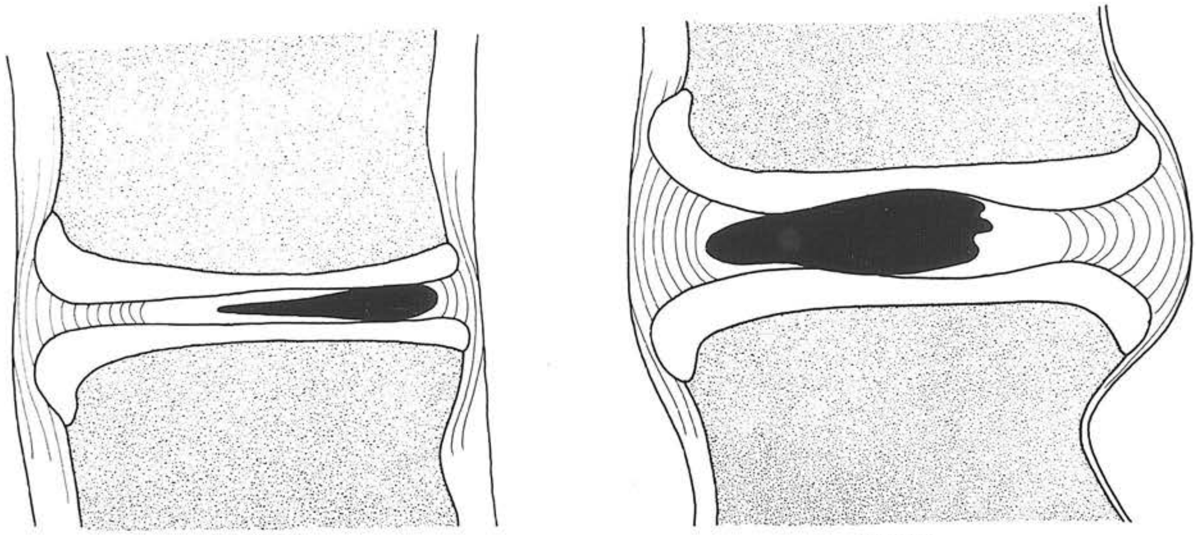
295 mm CRL





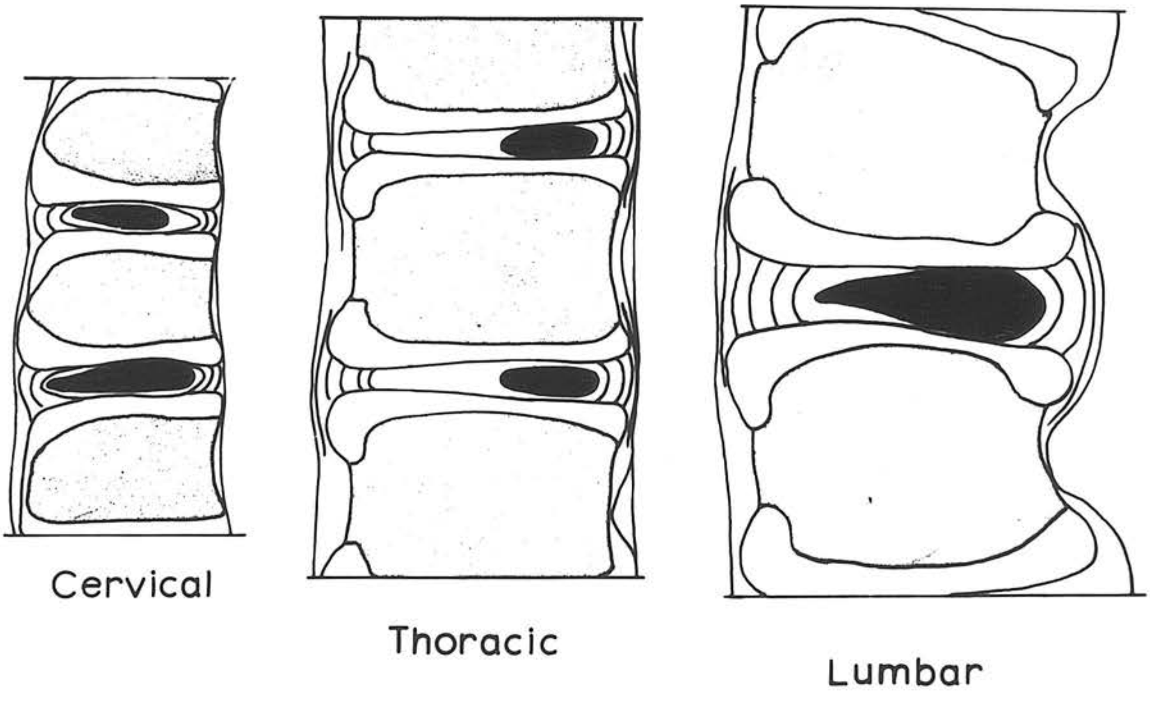
THORACIC LUMBAR

A FULL TERM FOETUS



THORACIC LUMBAR

A THREE YEAR NINE MONTH CHILD



A FOURTEEN MONTH INFANT

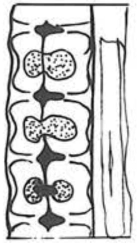
Text-fig. 61 (i - iii)

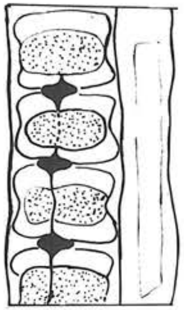
Tracings of Notochordal Remnants in Median Sagittal Sections of Thoracic Vertebral Columns at Various Ages. (anterior is to the left)

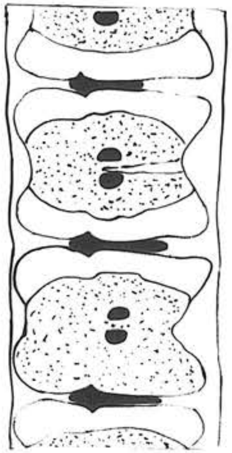
x 4

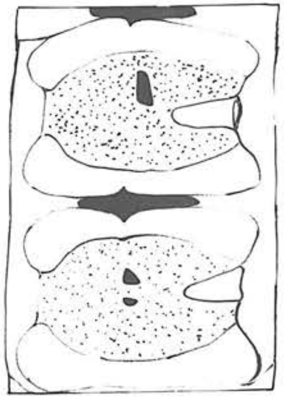
The following cases are illustrated :

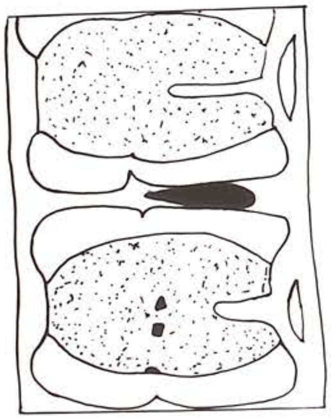
Case no.	Age
1 T	18w. foetus
2 T	22w. "
7 T	30w. "
16 T	35w. "
21 T	40w. "
40 T	$3\frac{1}{2}$m. infant
46 T	14m. "
54 T	3yr.4m. child
59 T	$7\frac{1}{2}$ year "


1 T

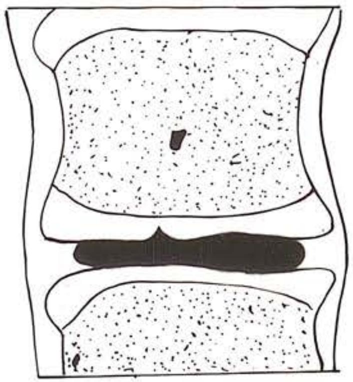

2 T


7 T

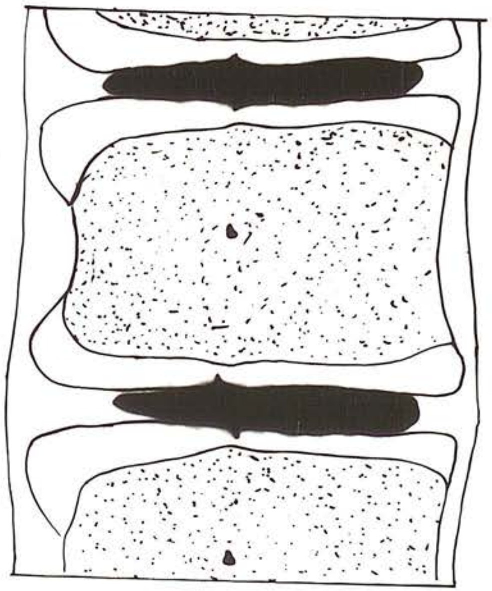

16 T



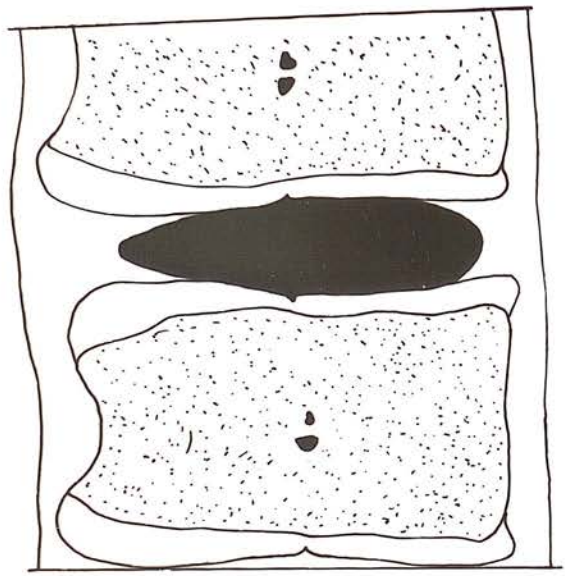
21 T



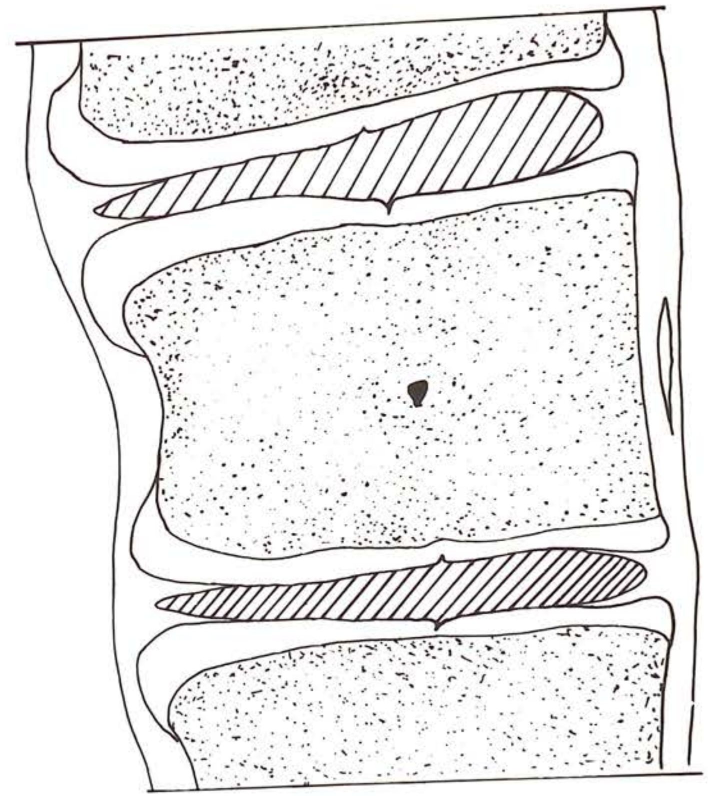
40 T



46 T



54 T



59 T

Text-fig. 62

The 'Line of the Notochord' (in the Thoracic Region).

A diagrammatic summary of the changes during growth in the relative position in median sagittal sections of:-

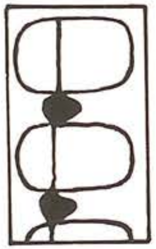
(i) cartilage nodules in vertebral bodies, and

(ii) funnel shaped depressions in 'cartilage layers',

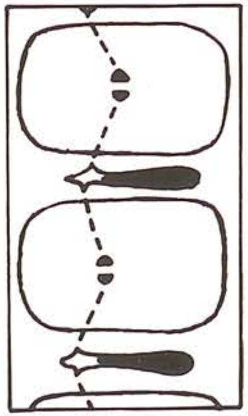
based on the information in Text-fig. 61 (anterior is to the left).

This suggests that from 20 weeks to 40 weeks more tissue is added anterior to the 'line of the notochord' at vertebral levels than at intervertebral levels.

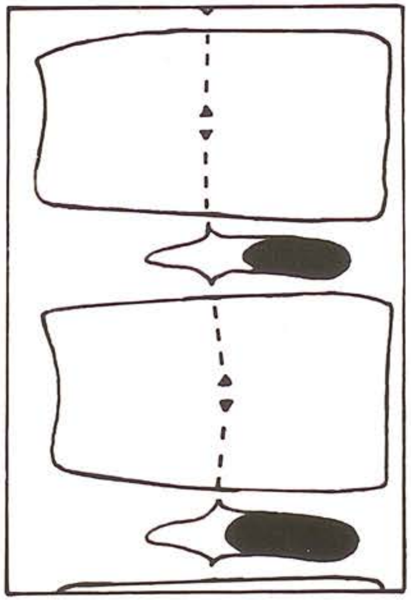
Notochordal Remnants (T.)



20 w.



40 w.



3 yrs.

D. SUMMARY OF THE AGE CHANGES IN THE DISCS AND VERTEBRAE

(though all cases were carefully examined, a description of each one would be unduly repetitive)

1. Anulus Fibrosus:

The outer layers of the anulus fibrosus appear entirely fibrous, with collagen bundles which are coarse and which usually remain unstained by light green. The collagen bundles of the middle and inner layers are fine, stain well with light green, and are embedded in a plentiful basophilic matrix with numerous fibroblasts (Text-figs. 63&64).

The lamellae of the inner two-thirds of the 'anatomical anulus' appear to be continuous with horizontal lamellae in the 'cartilage layers' (Text-fig. 83) when viewed by polarised light. These characteristics of the anulus appear in the foetus and persist into childhood without dramatic change.

The outer anulus is vascular in the foetus (Text-fig. 99), but its blood vessels are reduced in number to a scattered few between the outer lamellae as the anulus grows in the infant.

2. 'Inner cell zone':

This zone lies between the 'lamellar anulus fibrosus' and the notochordal nucleus pulposus ('FC' in Text-fig. 11). It is included in the measurement termed 'total anulus' (Table 10 & Text-fig. 9b).

In the youngest embryos this 'inner cell zone' (Walmsley; 1953) 'transitional zone' (Peacock; 1951) or 'perichordal zone' (But; 1959) consists of embryonic hyaline cartilage. In foetuses and infants it is a cellular fibrocartilaginous region of variable extent. There are few collagen bundles in early foetuses but the collagen content increases with increasing maturity. The collagen bundles are not oriented in a well defined concentric lamellar pattern but may show either a random orientation or a wavy horizontal orientation.

The 'inner cell zone' lies principally anterior to the notochordal nucleus pulposus (in thoracic discs at all stages and in foetal and infant lumbar discs (i.e. in regions of vertebral kyphosis)). In many prenatal cervical discs, where the notochordal segment remains rudimentary and anterior, the 'inner cell zone' occupies the centre of the disc, and in some newborn or infant cervical discs it entirely replaces the notochordal nucleus pulposus. In foetal and infant discs there is a gradual change in the appearance of this zone as it is traced from the anulus to the notochordal nucleus. The cells adjoining the anulus appear to be arranged in rows parallel to the inner lamellae of the anulus; nearer the notochordal nucleus pulposus the cells have a random orientation; and at the boundary of the nucleus there is some mixing of the 'cartilage' cells with the notochordal cell clumps. The 'inner cell zone' tissue bounding the notochordal nucleus pulposus often has a hyaline, necrotic appearance with indistinct cell boundaries. Strands of this tissue are seen within the notochordal nucleus pulposus, apparently 'peeling off' into it. These strands are usually necrotic and disintegrating. In some newborn and infant lumbar discs, where a particularly large notochordal nucleus pulposus is found, the 'inner zone' is sparse and the mucoid matrix abuts almost directly on the inner lamellae of the anulus.

In lumbar discs of two years and older, a less cellular more collagenous zone is seen lying principally posterior to the notochordal nucleus pulposus. From about three to five years irregular masses of this tissue project into the notochordal area from behind, giving an appearance of forward displacement of the lumbar notochordal nucleus pulposus. Eventually, by seven to ten years, the area formerly occupied by notochordal tissue appears to be filled with a relatively acellular fibrocartilage.

3. Notochordal Nucleus Pulposus: The outlines in Text-figs. 44-49 illustrate the typical shape, extent and position of the notochordal nucleus pulposus as seen in horizontal and median sagittal sections at different stages from foetal life to childhood. Text-figs. 60(i-iv) compare median sagittal outlines of notochordal segments in cervical thoracic and lumbar regions at various stages.

TABLE 20

APPROXIMATE HORIZONTAL EXTENSION OF NOTOCHORDAL NUCLEUS PULPOSUS AT EACH STAGE OF DEVELOPMENT

	(A.P.D. of Nucleus/ A.P.D. of Disc)				
Region	Embryo (8-10w.)	Foetus (18-23w.)	Newborn	Infant (1 yr.)	Child (3-4 yrs.)
Lumbar	1/7	1/4	1/2	3/4	2/3
Thoracic	1/7	1/3	1/3	1/3	2/3
Cervical	1/7	1/5	0 - 1/2	0 - 2/3	0 - 2/3

(a) Lumbar Notochordal Nucleus Pulposus (L 4-5): In the embryo, the original fusiform notochordal segment becomes globular and extends principally backwards from the mucoid streak (as seen in midline sagittal sections) as it increases in size and cell content to form a centrally situated oval or elipse (growth of the whole disc is likewise principally in a posterior direction from the mucoid streak at this stage). In the foetus, notochordal cells continue to increase in number and are formed into a 'chorda reticulum' by the increase in mucoid matrix between and around them. The newborn notochordal nucleus pulposus is wedge-shaped in median sagittal section, large and rounded towards the posterior anulus and tapering forwards into the 'inner cell zone'. Perinatally and in infancy, there is a great increase in the volume of the notochordal nucleus pulposus, principally by accumulation of clear mucoid matrix, though there is probably some further increase in the number of notochordal cells. Much of the 'chorda reticulum' is split up into small clumps of notochordal cells distributed throughout the clear mucoid matrix. Peripherally, small necrotic strands of 'inner cell zone' tissue may project into it, and in some discs isolated strands of fibrocartilage may traverse the notochordal nucleus pulposus from one cartilage plate to the next, their appearance suggesting that they previously formed a part of the anulus and are 'left behind' as the notochordal tissue expands. In infants the nucleus is often oval with its long axis horizontal in median sagittal section, but is flattened above and below where it adjoins the 'cartilage layers'. It occupies most of the antero-posterior extent of the disc in midline sections.

In late infancy and early childhood there is a considerable but gradual change in the character of the notochordal nucleus pulposus. Though there is further increase in mucoid matrix and consequently in total volume of the 'notochordal tissue' (Text fig. 74), collagen bundles are now seen within it, and the notochordal cells may appear smaller in some discs and occasionally show nuclear pyknosis and loss of cytoplasmic staining. In discs from lordotic lumbar vertebral colums (1 year 8 months and older) the notochordal nucleus pulposus is found in a central or relatively anterior position compared to earlier stages, and may be wedge-shaped, large and rounded against the anterior anulus, and tapering backwards, a mirror image of the shape found at birth. In young children (e.g. at 3 years 9 months) fibrocartilaginous masses project into the notochordal nucleus pulposus from the area of rather structureless fibrocartilage which is now seen between the posterior lamellar anulus and the notochordal area. These projections do not stain well, and may be necrotic at their edges where they are in contact with notochordal tissue. By about five years the lumbar notochordal nucleus pulposus may be restricted to an anterior position with an increase in the soft fibrocartilage which lies behind it (cf. case 58 (5 years) which shows a further increase in the volume of its notochordal nucleus pulposus, principally by increase in its height). After this time the notochordal nucleus declines in volume. Its cells disintegrate and disappear and a soft fibrocartilage containing scattered cartilage cells occurring singly or in small groups occupies the centre of the disc.

(b) Thoracic Notochordal Nucleus Pulposus: Compared to lumbar discs, the trends are broadly similar prenatally, but the thoracic notochordal nucleus pulposus shows a lesser increase in volume, and a lower or flatter nucleus develops towards the posterior half of the disc. In the foetus, newborn, and infant, the notochordal nucleus pulposus is more obviously confined to the posterior half of the thoracic disc (T 8-9). In early childhood there is an increase in its mucoid matrix which occurs later and is usually less 'dramatic' than in the lower lumbar discs. Though the increasing amount of mucoid material extends forwards in the disc, the main thoracic notochordal cell mass remains more discrete and posterior in position, relatively few notochordal cell clumps mixing with the clear mucoid matrix anteriorly. At about the middle of the first decade of life, fibrocartilaginous transformation of the nucleus pulposus takes place in the thoracic discs as in the lumbar discs.

(c) Cervical Notochordal Nucleus Pulposus: The notochordal segment remains rudimentary for some time and does not usually expand until late foetal life. It may develop by birth into a fairly flat central elipse as seen in midline sections, but in some newborn and infant cervical discs no notochordal cells or clear mucoid matrix can be found and the central region of the disc is occupied solely by 'inner cell zone' tissue. The appearance of the large notochordal nucleus pulposus in the 14 month and 3 year 9 month cases is therefore quite surprising. These notochordal nuclei pulposi are wedge shaped in median sagittal section, rounded anteriorly and tapering backwards, and the surrounding tissues show quite extensive changes in staining reaction with necrosis where they bound the notochordal area (Text-fig. 77). No cervical discs older than three years nine months are included in this series.

The 'delayed' development of the notochordal segments in the cervical region compared to the other regions of the vertebral column corresponds to a similar relative delay in extension of ossification in the cervical centra as seen from Table 21.

4. The Cartilage Plates: (see Text fig. 79 a & Table 9) The cartilage plates consist of growth plates and 'cartilage layers'.

(a) 'Cartilage Layers': As viewed in midline sections, the cartilage layers are thicker near their anterior and posterior margins than at their 'centres'. When the notochordal nucleus pulposus is large, the thinnest part of each 'cartilage layer' corresponds to the maximum 'bulge' of the notochordal nucleus. In some children (e.g. the 3 year 9 month lumbar disc) the growth plate (as well as the 'cartilage layer') is also thinnest opposite the 'bulge' of the large notochordal nucleus pulposus. In some discs, (Text figs. 70&73) strands of the 'cartilage layer' adjoining the notochordal area appear to be 'peeling off' into the mucoid matrix of the notochordal nucleus. When viewed by polarised light (Text-figs. 82 - 84) the 'cartilage layer' is seen as a horizontally lamellated structure whose lamellae appear to be continuous with the similar 'light and dark bands' of the inner anatomical anulus.

(b) Growth Plates: (as seen in median sagittal section) The cartilage columns are mostly oriented vertical to the ossification front, but the most peripheral columns deviate, where they adjoin the cartilage layers, towards the centre of the disc proper.

At birth and in early infancy, those cartilage columns above and below the notochordal area often deviate slightly towards the nearer anterior or posterior surface of the disc proper.

5. Bony Vertebral Bodies (Centra) Ossification from the centra reaches the anterior and posterior surfaces of the vertebral column before birth (except in the cervical region - see table 21).

TABLE 21

Vertebra	Extension of The Centrum	
	To the Anterior Border of V.C.	To the Posterior Border of V.C.
Cervical (C5)	after five months	30 to 34 weeks
Thoracic (T8)	about 29 weeks	18 to 22 weeks
Lumbar (L4)	22 to 25 weeks	18 to 22 weeks

(the centrum does not extend to the lateral border of its cartilage model until early infancy)

In infants the cephalic and caudal surfaces of the bony vertebral bodies (as seen in midline sections) are convex. Lumbar centra become gradually less convex in late infancy and their cephalic and caudal surfaces are almost flat by the third year of life except at the periphery. These surfaces become progressively more concave as seen in sagittal sections and lateral X-rays from three to five years. The concavity may be apparent from three years in sectioned material but is not readily seen until later in lateral X-rays (Text-fig. 88). In later childhood this concavity is marked. It appears to develop originally opposite the 'bulge' of the notochordal nucleus in normally lordotic vertebral columns, where the cartilage layer, and sometimes also the cartilage growth plate are earlier observed to be thinner than elsewhere in the same disc. Thoracic centra are almost rectangular by about one year, though their anterior heights are less than their posterior heights. Their caudal and cephalic surfaces develop slight concavities later but these are not marked. The cervical centra remain convex on their cephalic surfaces, with a characteristic downward slope of this surface anteriorly. Their caudal surfaces become concave by about four years (as seen in lateral X-rays).

Schmorl's nodes in adults: Intraspongious prolapses of disc tissue are quite frequently found in adult thoracic and lumbar vertebral bodies. These are seen in the median plane and are often both multiple and vertically aligned in successive vertebrae, (Text-fig. 90). Deeply indented depressions of the vertebral end surfaces are also seen in similar situations (Text-fig. 91).

Text-fig. 63

The Anulus Fibrosus of a Full Term Foetus.

Case no. 29, disc L 3-4. 200 micron section, stained haematoxylin and light green.

(a) the anterior anulus fibrosus, x 24.

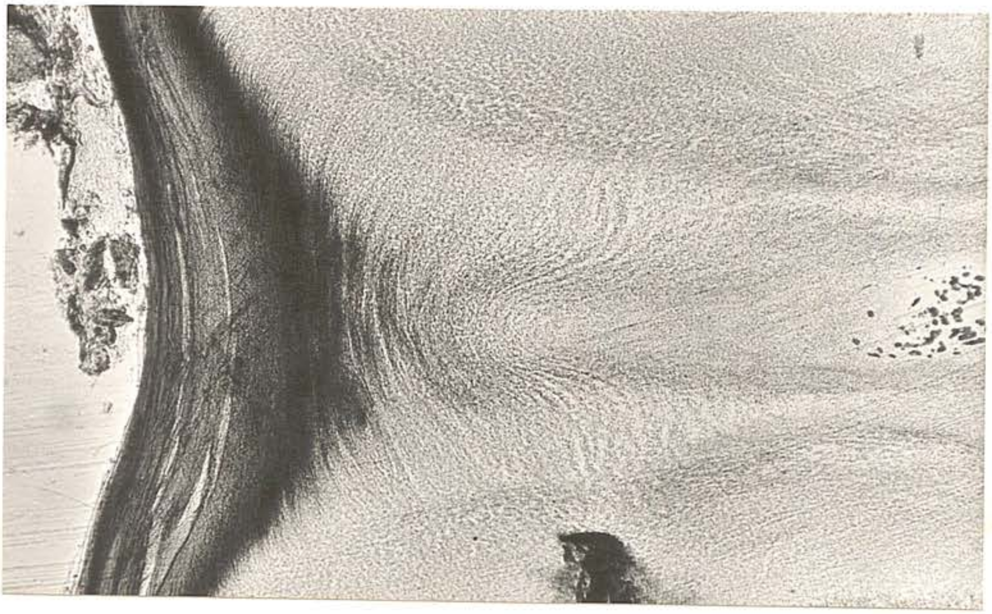
From left to right a gradual change can be traced from lamellae of coarse collagen bundles with few cells, to lamellae of fine collagen bundles in a cellular matrix, changing to a cellular area in which no well defined orientation of cells or fibres can be seen, the 'inner cell zone', bounding the notochordal nucleus pulposus. The outer anulus (including the anterior longitudinal ligament) is relatively unstained, and the collagen bundles of the middle and inner anulus take up relatively more stain.

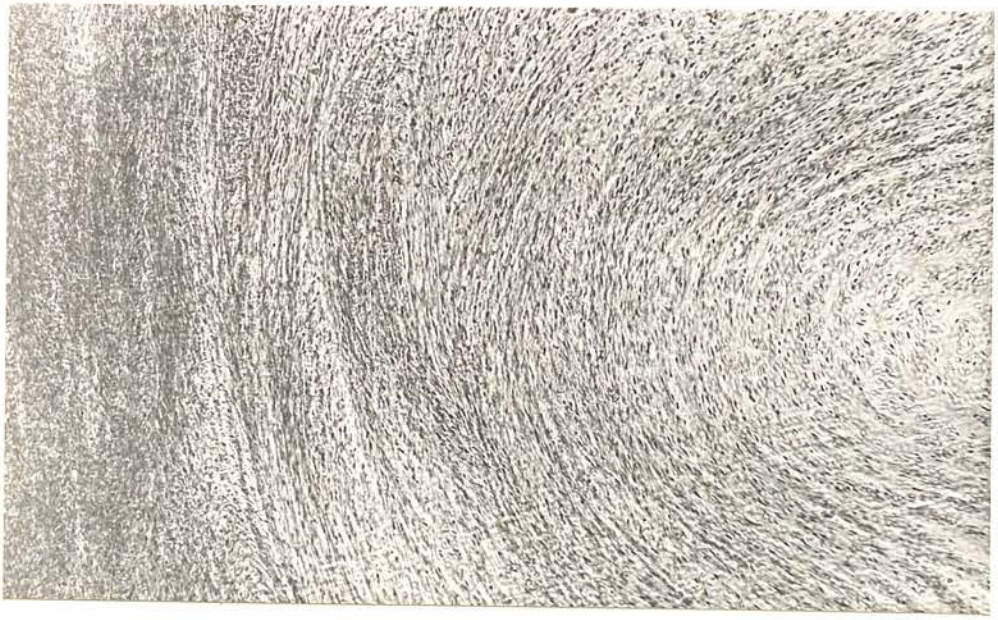
(b) The inner part of the anterior anulus fibrosus shown above. x 75

From left to right there is:-

(i) increasing cellularity

(ii) decreasing density of collagen bundles.





Text-fig. 64

The Anulus Fibrosus (continued).

(a) The outer part of the full term foetal anterior anulus fibrosus shown in Text-fig. 63.

x 75.

From left to right there is:-

(i) increasing cellularity

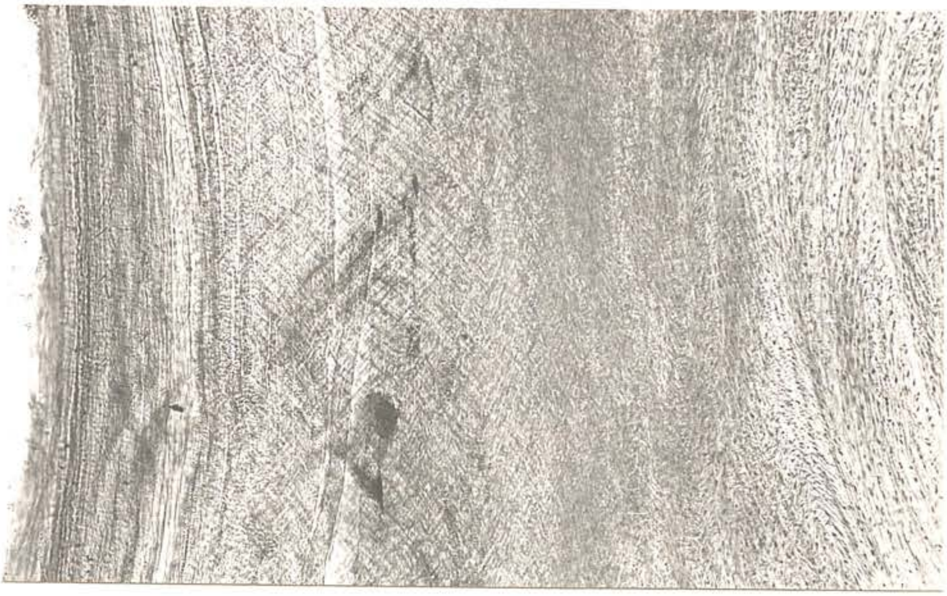
(ii) decreasing courseness of collagen bundles.

(b) The posterior anulus fibrosus of a child of 4 years 9 months (case no. 57, disc L 4-5).

x 25.

Note: (i) the relative courseness of the collagen bundles

(ii) the relative lack of cells and matrix, as compared to the infant anulus fibrosus.



Text-fig. 65

The 'Inner Cell Zone'

(a) A median sagittal section of a 36 week foetal lumbar disc in which development of the notochordal nucleus pulposus appears retarded, and the inner cell zone is more widespread than usual for this age.

Case no. 19, x 24.

Most of the centre of this disc (to the left of the notochordal tissue) is occupied by inner cell zone tissue.

(b) A median sagittal section of a normal 30 week foetal cervical disc.

Case no. 6, x 75.

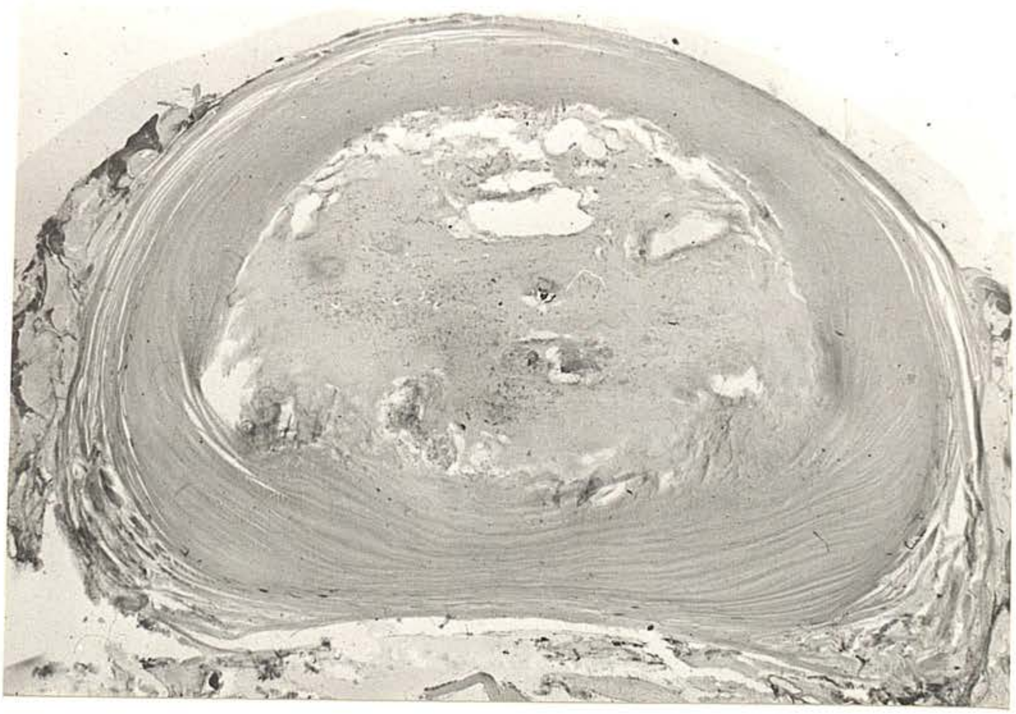
Posterior to the curved notochordal segment, the centre of the disc is occupied by inner cell zone tissue.

Text-fig. 66

The Notochordal Nucleus Pulposus.

(a) A horizontal section of a 30 week foetal lumbar disc.
Case no. 8, x 8. (see also Text-fig. 69)
A largely cellular notochordal nucleus pulposus is seen, with inner cell zone tissue lying anterior to it, (see text-fig. 9).

(b) A horizontal section of a three year 4 month lumbar disc.
Case no. 54, x 3.3.
The notochordal nucleus pulposus is largely mucoid, and also in contrast to 66(a), the posterior boundary of the notochordal nucleus pulposus is less well defined than its anterior boundary.



Text-fig. 67

Full Term Foetal Lumbar Nuclei Pulposi.

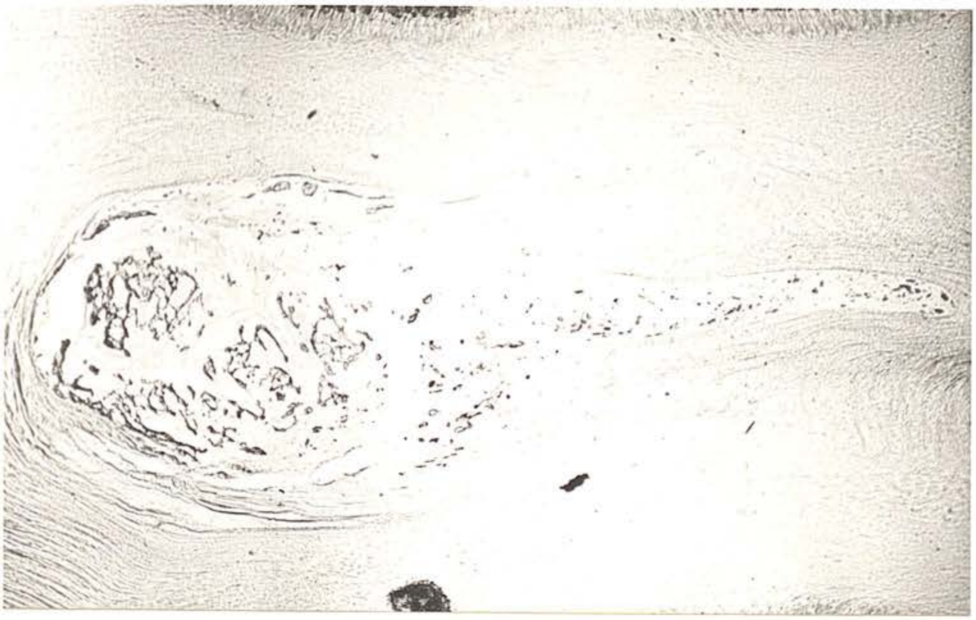
(anterior is to the right in each case)

(a) A sagittal section of the disc L 4-5 from a 35 week foetus.
Case no. 17, x 16.

(b) A median sagittal section of the disc L 4-5 from a 40 week foetus.
Case no. 29, x 15.

(c) A sagittal section of the disc L 3-4 from a 40 week foetus.
Case no. 34, x 17.

Note: The nuclei pulposi in (a) and (b), typical of this age group, are situated posterior to the centre of the disc, and taper to a point anteriorly. The nucleus in (c) is relatively large for this age, and its shape is more typical of a three to ten month nucleus.



Text-fig. 68

Lumbar Nuclei Pulposi - contrasting a full term foetus with a ten month infant.

(anterior is to the right in each case)

(a) A sagittal section of the disc L 4-5 from a 40 week foetus.

Case no. 23, (200 micron section) x 19.

(b) A sagittal section of the disc L 3-4 from a ten month infant.

Case no. 45, (150 micron section) x 19.

The increase in the size of the notochordal nucleus pulposus appears to be associated with an increase in its mucoid matrix.

Text-fig. 69

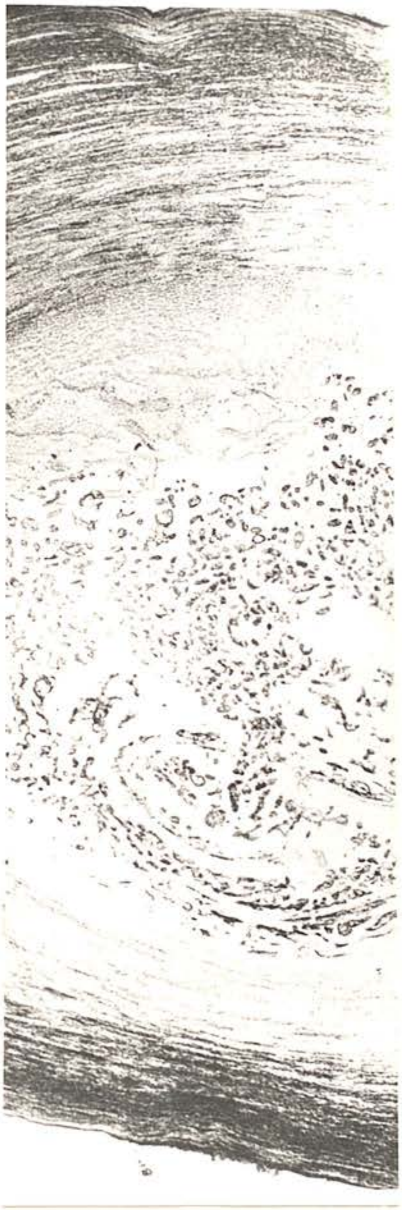
Changes at the Periphery of the Notochordal Nucleus Pulposus.

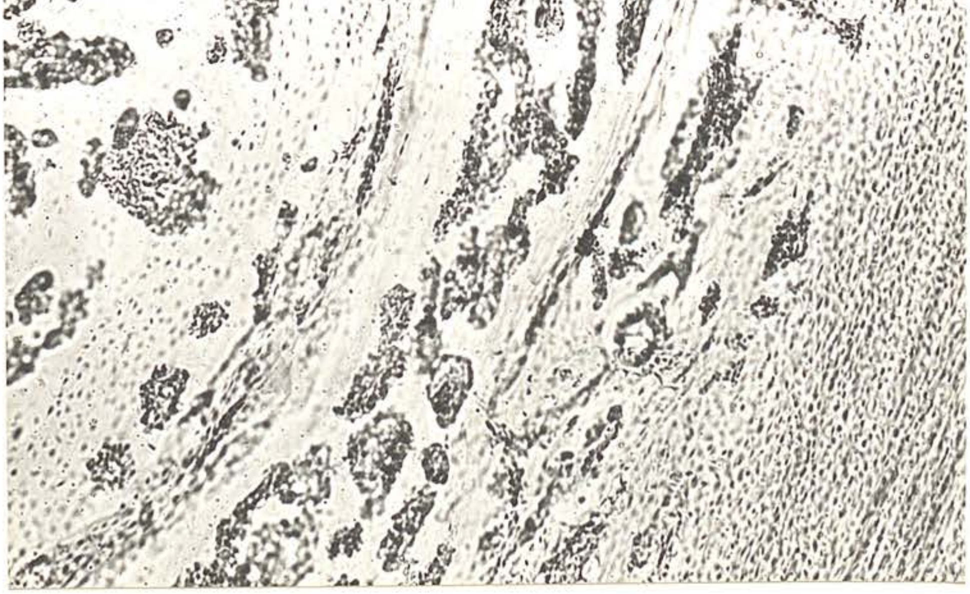
- in a horizontal section of a 30 week foetal lumbar disc.

(a) Part of a horizontal section (in the region of the median plane) of the L 4-5 disc (case no. 8) - see also Text-fig. 66. 50 micron section, x 18.

(b) Part of the notochordal nucleus pulposus/inner anulus boundary from the same section showing the intermingling of notochordal tissue with 'loose' cellular lamellae of the inner anulus fibrosus. Necrotic changes are visible in some lamellae. x 50

(c) Another part of the notochordal nucleus pulposus/anulus fibrosus boundary from the same section showing mixing of the two tissues, or 'invasion' of the inner anulus by the expanding notochordal nucleus pulposus. x 80.



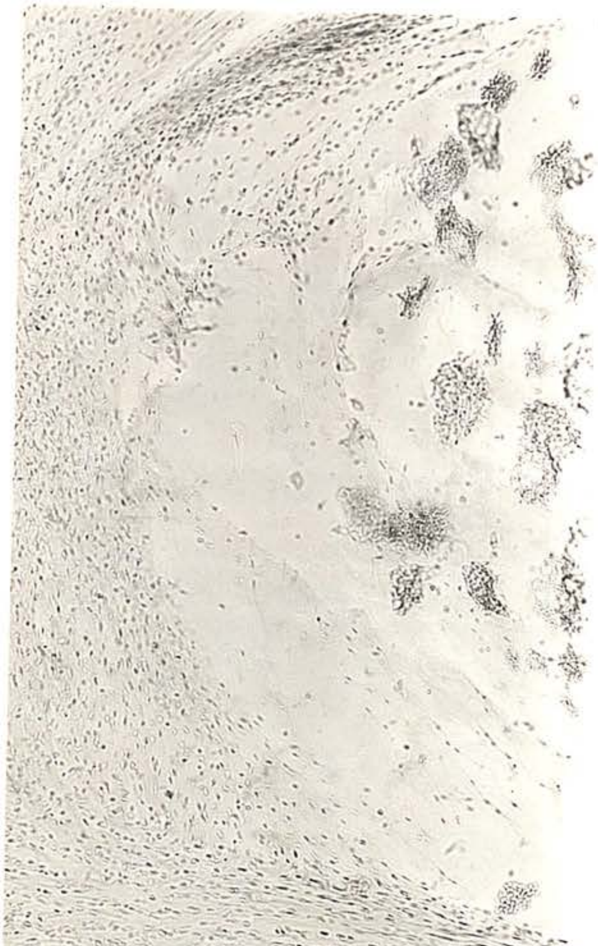


Text-fig 70

Changes at the boundary of the Foetal Notochordal Nucleus Pulposus, - in sagittal section. (cf. Text-fig. 67 (a))

(a) L 4-5 disc, case no. 17 (35 weeks) x 90.
Loosening of lamellae at the surface of the upper 'cartilage layer'.

(b) L 4-5 disc, case no. 17 (35 weeks) x 90.
Loosening and disintegration ('liquefaction') of inner cell zone tissue at the posterior boundary of the notochordal nucleus pulposus.



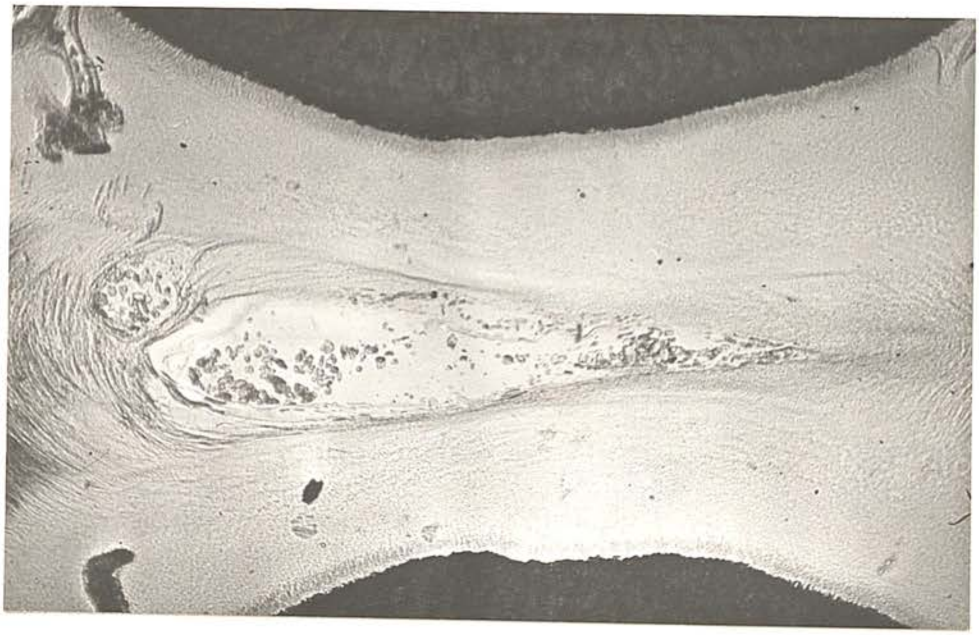
Text-fig. 71

Changes at the Boundary of the Notochordal Nucleus Pulposus, - in sagittal section.

(a) L 4-5 disc, case no. 27 (40 weeks), x 15.

(b) The posterior part of the notochordal nucleus pulposus shown above, x 55.

The illustrations show 'invasion' of the posterior anulus fibrosus by notochordal tissue and necrosis of inner anulus fibrosus tissue where it adjoins the notochordal nucleus pulposus.



Text-fig. 72

Changes at the Boundary of the Notochordal Nucleus Pulposus,

- in sagittal section.

(a) L 4-5 disc, case no. 25 (40 weeks)

- see also Text-fig. 68 (a).

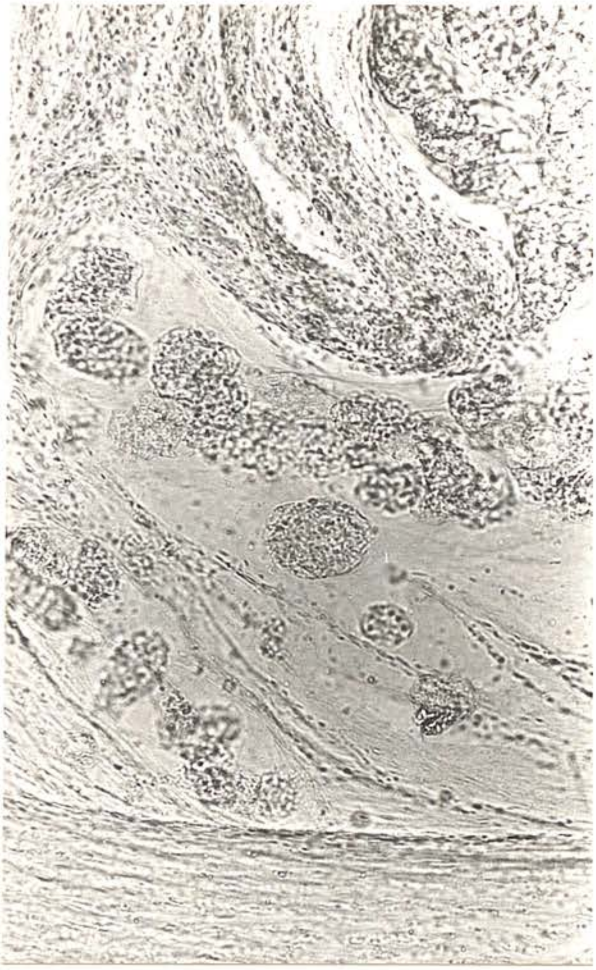
200 micron section, x 80.

An 'infolding' of the inner margin of the posterior anulus fibrosus into the notochordal nucleus pulposus is seen.

(b) L 4-5 disc, case no. 46 (14 months), x 20.

The anterior notochordal nucleus/anulus fibrosus boundary.

Necrotic changes are visible in the inner anulus fibrosus, and parts of this necrotic tissue are seen projecting into the notochordal nucleus pulposus.



Text-fig. 73

Changes at the Boundaries of the Notochordal Nucleus Pulposus,

- seen in sagittal section.

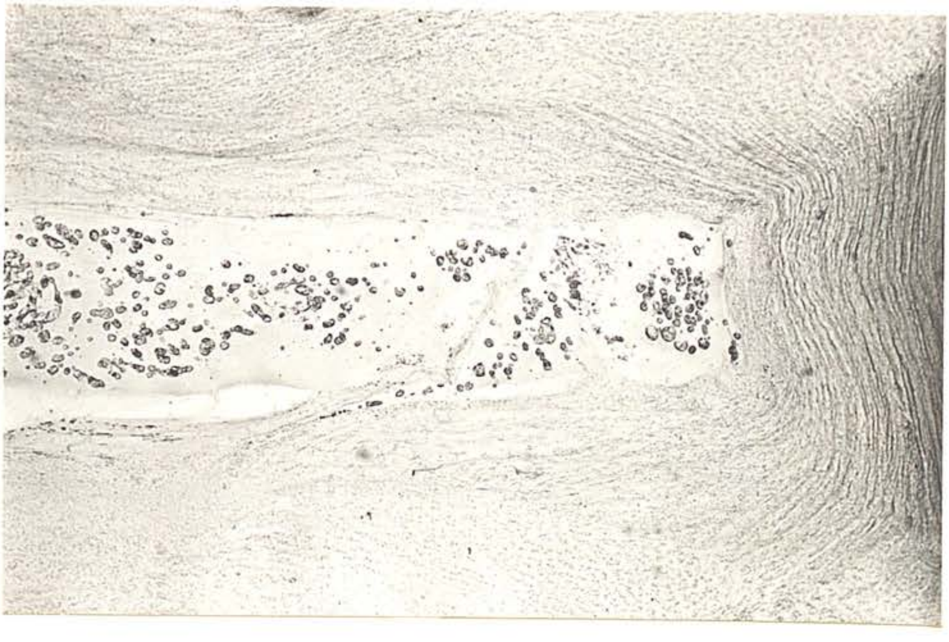
(a) L 4-5 disc, case no. 25 (40 weeks)

x 100.

A lamella of the upper cartilage plate, projecting into the nucleus pulposus among the notochordal cell clumps, shows necrotic changes.

(b) L 4-5 disc, case no. 41 (4 month infant), x 20.

A 'bridge' of necrotic fibrocartilage (probably formerly part of the anulus fibrosus) traverses the notochordal nucleus pulposus from one 'cartilage layer' to the other, and notochordal cell clumps are seen 'invading' the lower 'cartilage layer'.



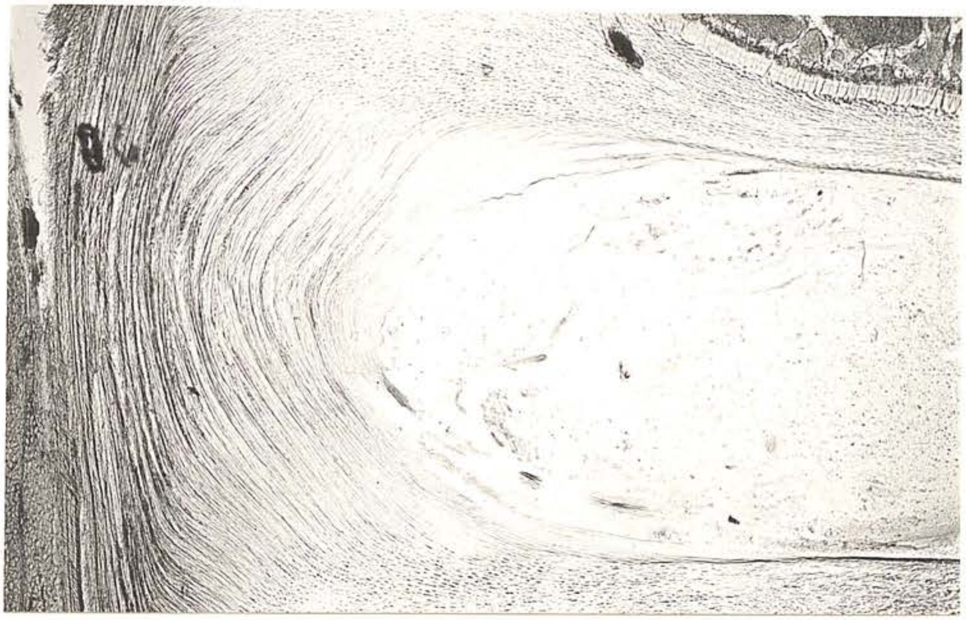
Text-fig. 74

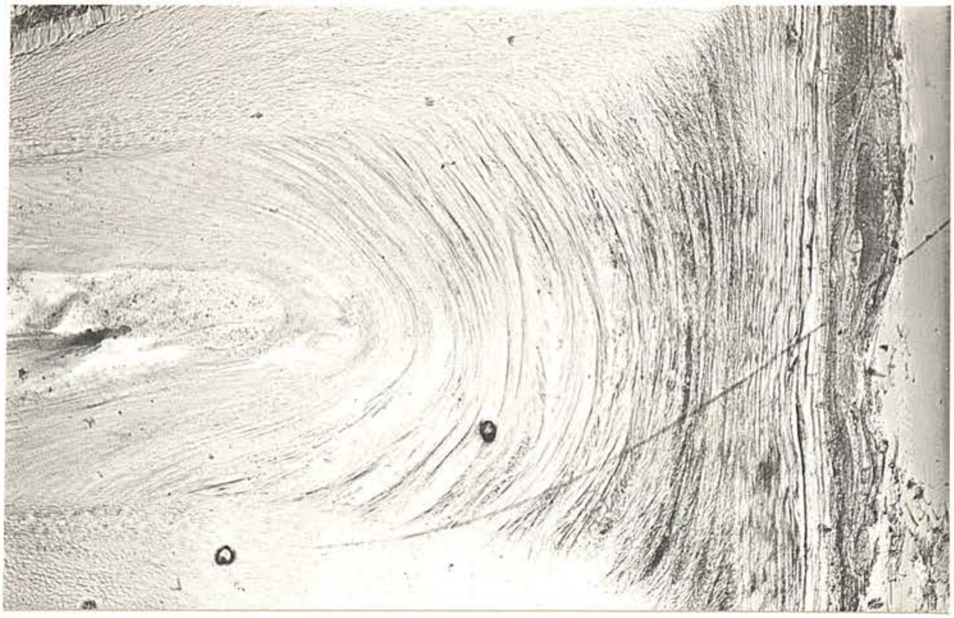
An Infant Lumbar Notochordal Nucleus Pulposus.

(a) L 4-5 disc, case no. 46 (14 month infant), x 15

The posterior end of the notochordal nucleus pulposus, in median sagittal section. The innermost lamella of the anulus fibrosus, which appears necrotic, lies well within the substance of the notochordal nucleus pulposus.

(b) In the same section (x 15), the tapering anterior end of the notochordal nucleus pulposus is seen. The tissue immediately bounding it is amorphous and necrotic.





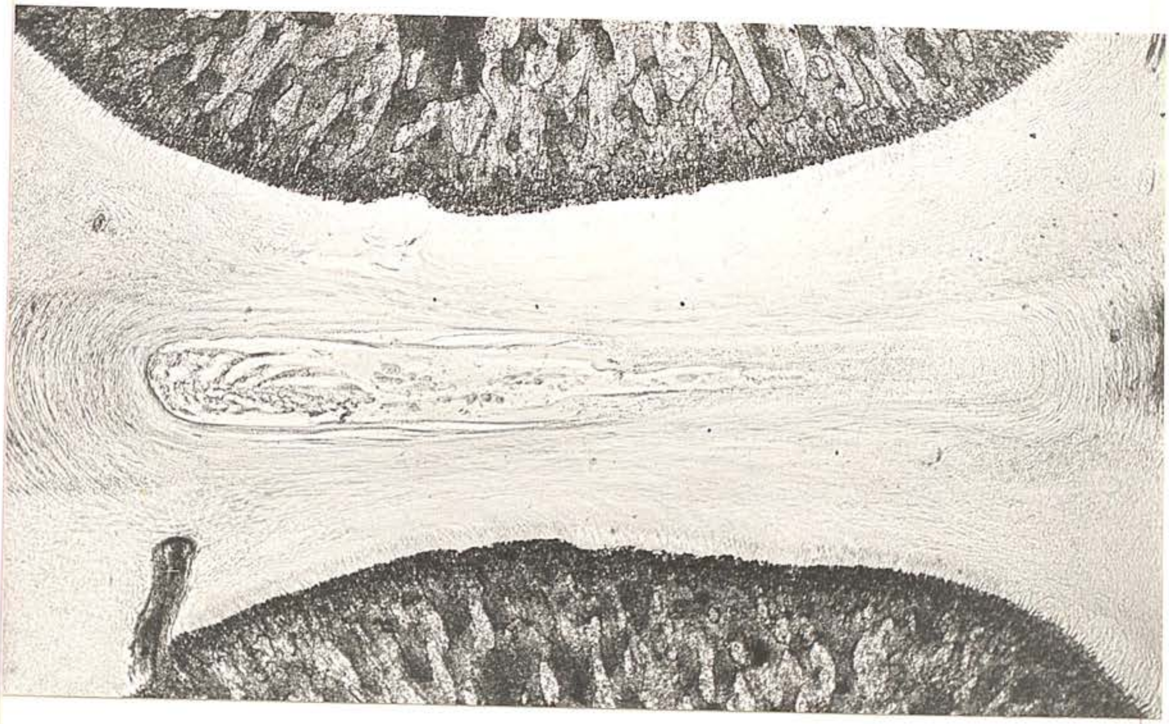
Text-fig. 75

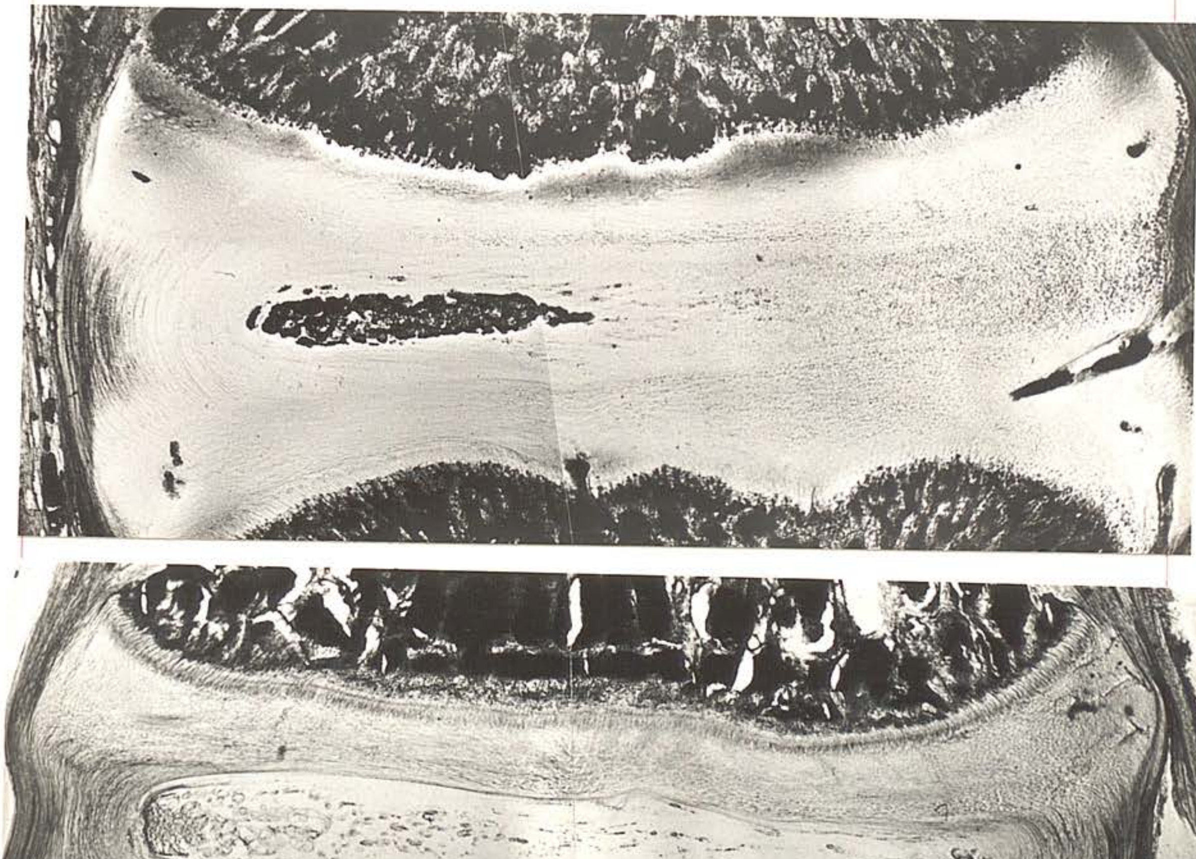
Thoracic Intervertebral Discs and Nuclei Pulposi in Sagittal Section (anterior is to the right in each case).

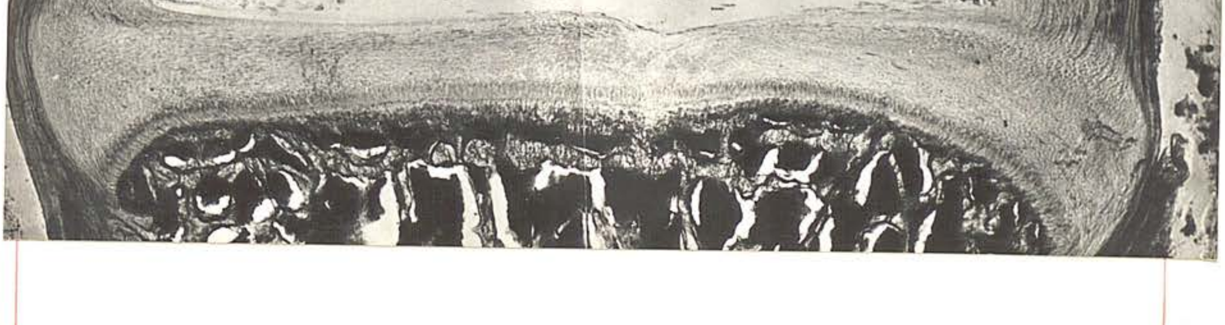
(a) T 8-9 disc, case no. 21 (40 weeks), x 17.
(haematoxylin and light green)

(b) T 8-9 disc, case no. 24 (40 weeks), x 14.
(haematoxylin, fuchsin and light green)
The dense, discrete, posteriorly situated mass of notochordal cells is stained by fuchsin.
As in 75 (a), a fairly extensive inner cell zone lies anterior to the notochordal nucleus pulposus.

(c) T 8-9 disc, case no. 40 ($3\frac{1}{2}$ month infant), x 12.
(haematoxylin and light green).
The notochordal nucleus pulposus is larger than in the full term foetuses, and contains more plentiful mucoid material, but most notochordal cell clumps remain in the posterior part of the notochordal nucleus pulposus.







Text-fig. 76

Cervical 'Notochordal Segments' in Median Sagittal Section.

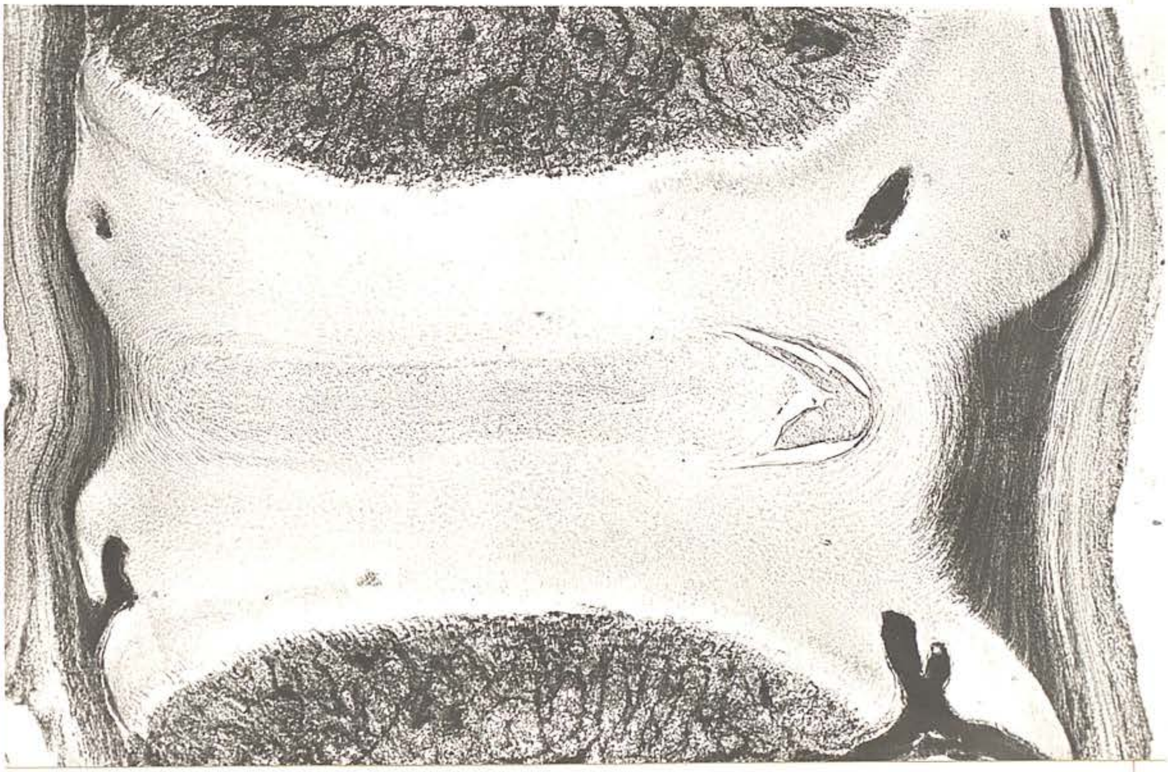
(anterior is to the right in each case)

(a) C 5-6 disc, case no 6 (30 week foetus), x 25.

(b) C 5-6 disc, case no. 14 (34 week foetus), x 24.

Note: (i) the anterior situation and crescentic shape of the notochordal segments.

(ii) that the centre of each disc is occupied by inner cell zone tissue (see also Text-fig. 65(b)).



Text-fig. 77

Cervical Notochordal Nuclei Pulposi in Sagittal Section.

(anterior is to the right in each case)

(a) C 4-5 disc, case no. 46 (14 month infant), x 25.

The central area of the disc near the median plane.

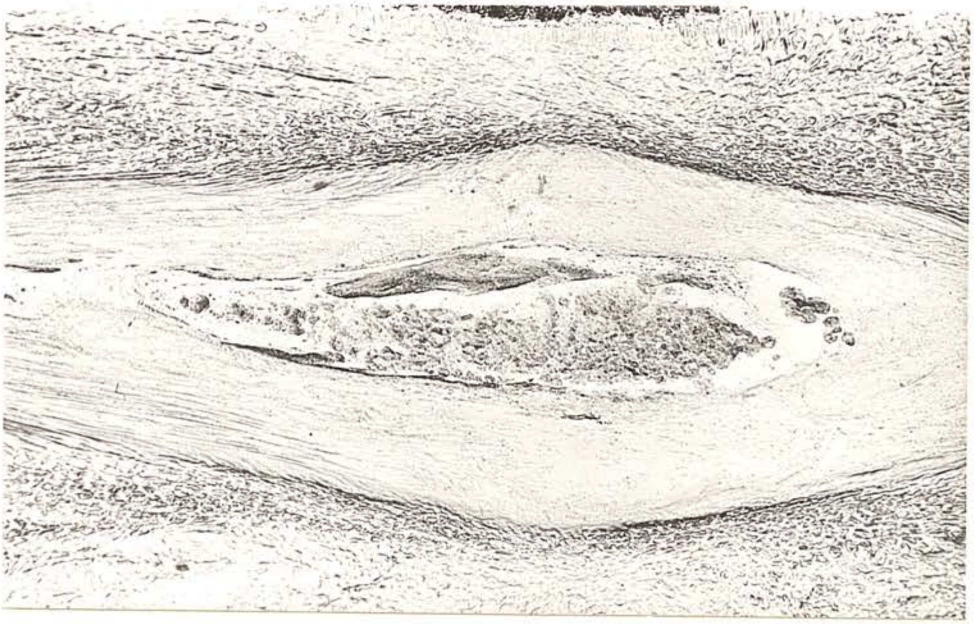
Note: (i) the central situation of the notochordal tissue.

(ii) the wide band of rather structureless tissue between the notochordal tissue and the 'cartilage layers'. This tissue appears necrotic where it bounds the notochordal nucleus pulposus.

(b) C 5-6 disc, case no. 55 (3 year 9 month child), x 11.

Note: (i) the anterior of centre situation of the notochordal tissue, and the 'wedge' shape of the nucleus pulposus.

(ii) the necrotic appearance of the tissue bounding this notochordal tissue, this necrosis extending to the surfaces of the 'cartilage layers'.



Text-fig. 78

Changes at the Boundary of the Cervical Notochordal Nucleus Pulposus,

- seen in sagittal section.

(a) C 5-6 disc, case no. 46 (14 months), x 25.

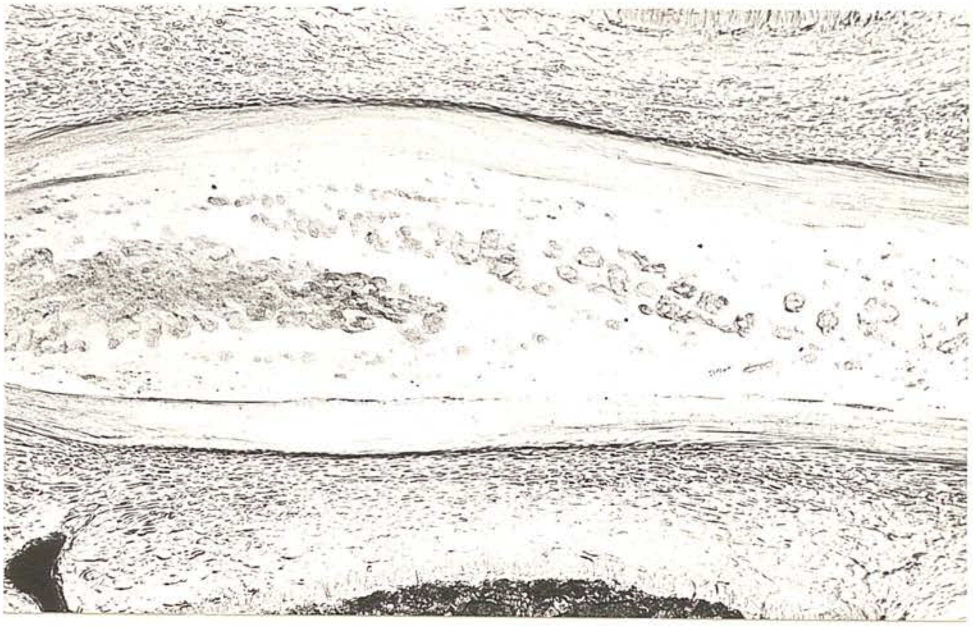
(cf. the disc above in Text-fig. 77 (a))

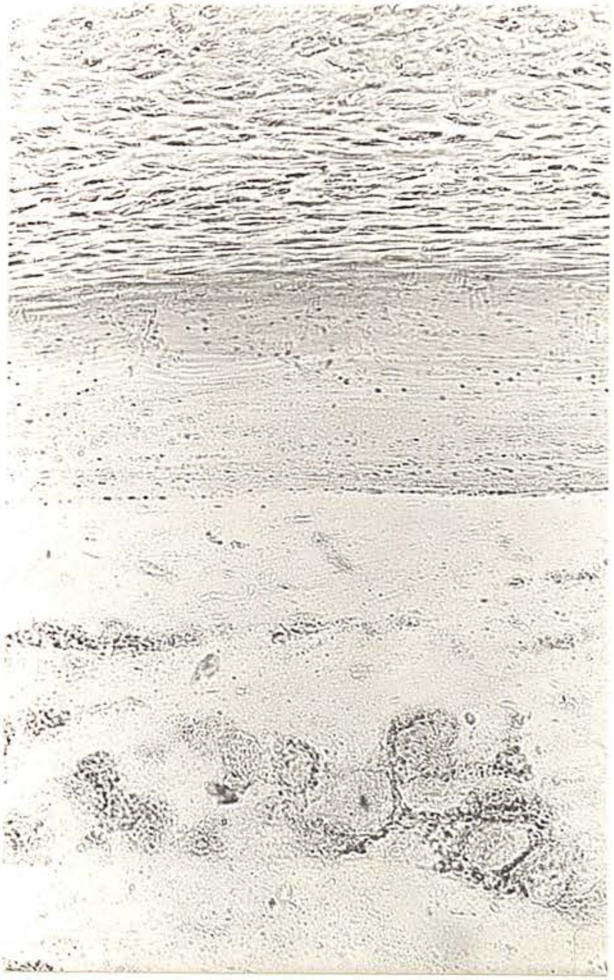
The central part of the disc near the median plane.

(b) Part of the section illustrated above

x 100.

The tissue bounding this large notochordal nucleus pulposus shows what appear to be extensive hyaline necrotic changes.





Text-fig. 79

The Cartilage Plates in Sagittal Section.

(a) L 4-5 disc, case no. 46 (14 month infant), x 60.

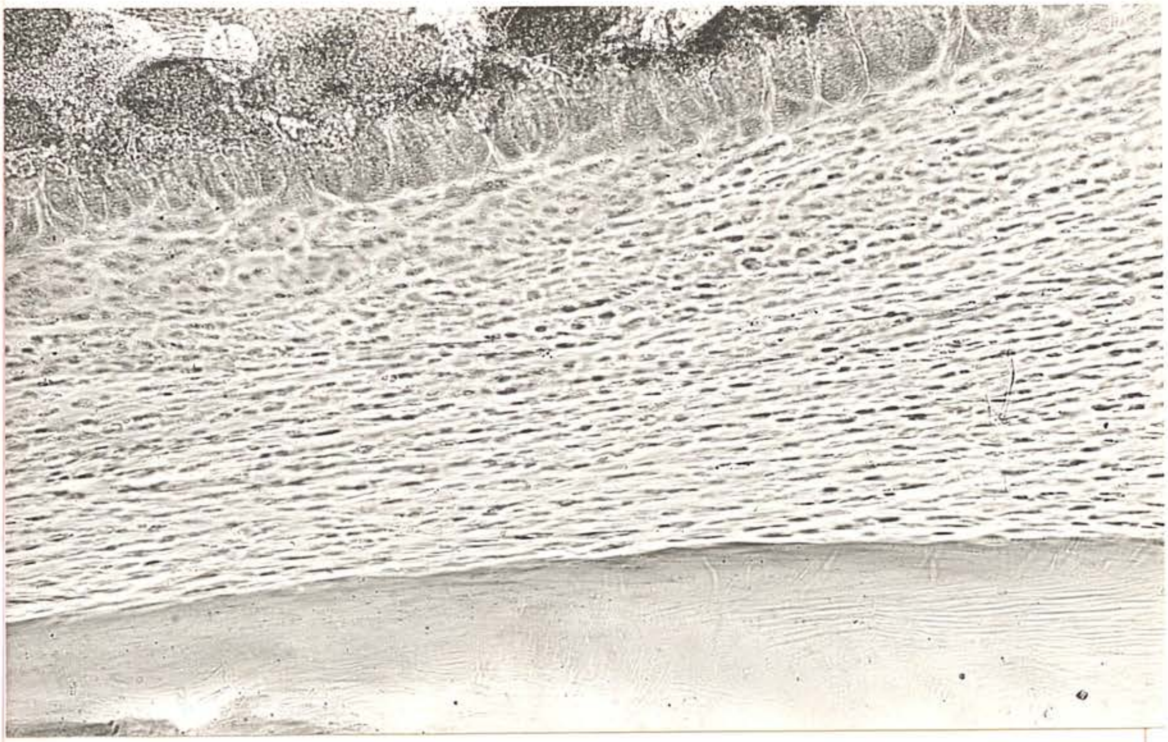
The upper cartilage plate including:

(i) the thicker 'cartilage layer' bounding the notochordal nucleus pulposus below, and,

(ii) the thinner growth plate above, in which cartilage columns are oriented approximately vertical to the ossification front. Both parts appear thinner to the left (opposite the maximum bulge of the notochordal nucleus pulposus).

(b) L 4-5 disc, case no. 57 (4 years 9 months), x 25.

This lower cartilage plate shows the funnel shaped defect (halving its thickness) which is at the site formerly occupied by the notochord.



Text-fig. 80

Deviation of the Cartilage Columns seen in Sagittal Sections.

(anterior is to the right in each case)

(a) T 8-9 disc, case no. 24, (40 weeks), x 25.

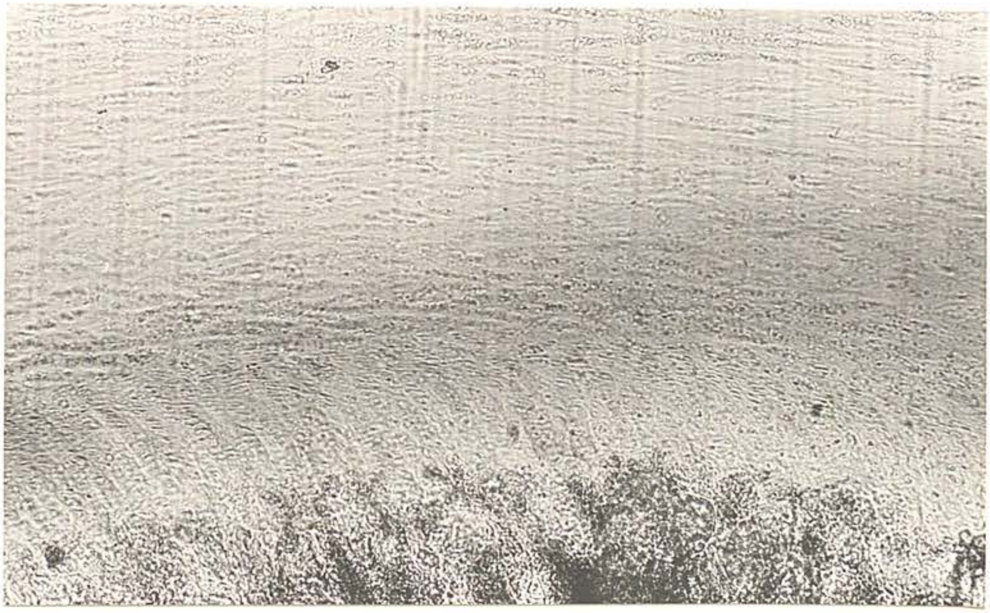
The posterior part of the lower cartilage plate showing:

(i) deviation of the cartilage columns in the right and centre of the field towards the posterior surface of the vertebral column, and

(ii) deviation of the cartilage columns at the left of the field away from the posterior surface of the vertebral column.

(b) A higher power view, x 100, of part of the growth plate shown in the centre of the illustration above.

Deviation of the cartilage columns to the left is seen.



Text-fig. 81

Deviation of the Cartilage Columns, seen in Sagittal Section.
(anterior is to the left in each case)

(a) L 4-5 disc, case no. 43 (5 month infant), x 26.

The posterior part of the lower cartilage plate showing deviation of the cartilage columns towards the posterior surface of the vertebral column.

(b) A higher power view, x 120, of the same growth plate. Deviation of the columns to the right is clearly seen.

Text-fig. 82

The Lamellar Structure of the 'Cartilage Layers'.

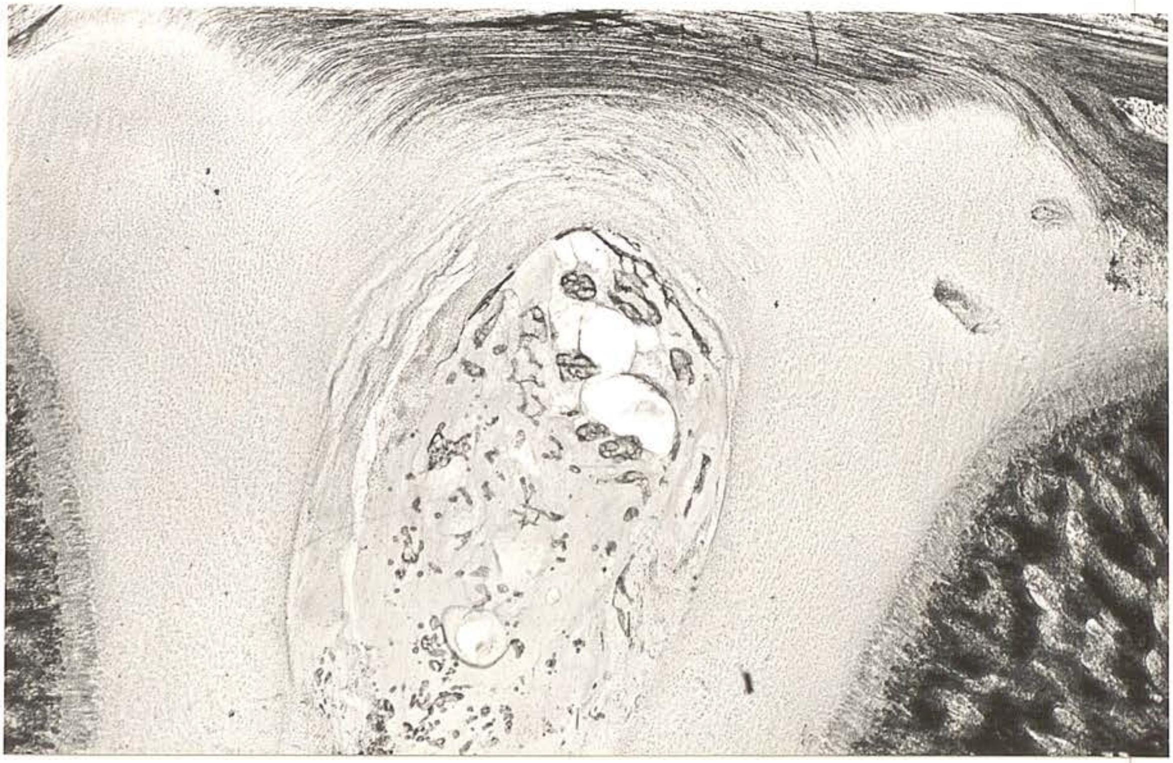
(a) L 4-5 disc, case no. 29 (40 weeks), sagittal section, x 20.

The posterior part of the disc: normal illumination.

(b) The same field illuminated by polarised light, showing:

(i) the lamellar structure of the 'cartilage layers' and,

(ii) their apparent continuity with lamellae of the inner two thirds of the anulus fibrosus.



Text-fig. 83

The Lamellar Structure of the 'Cartilage Layers'.

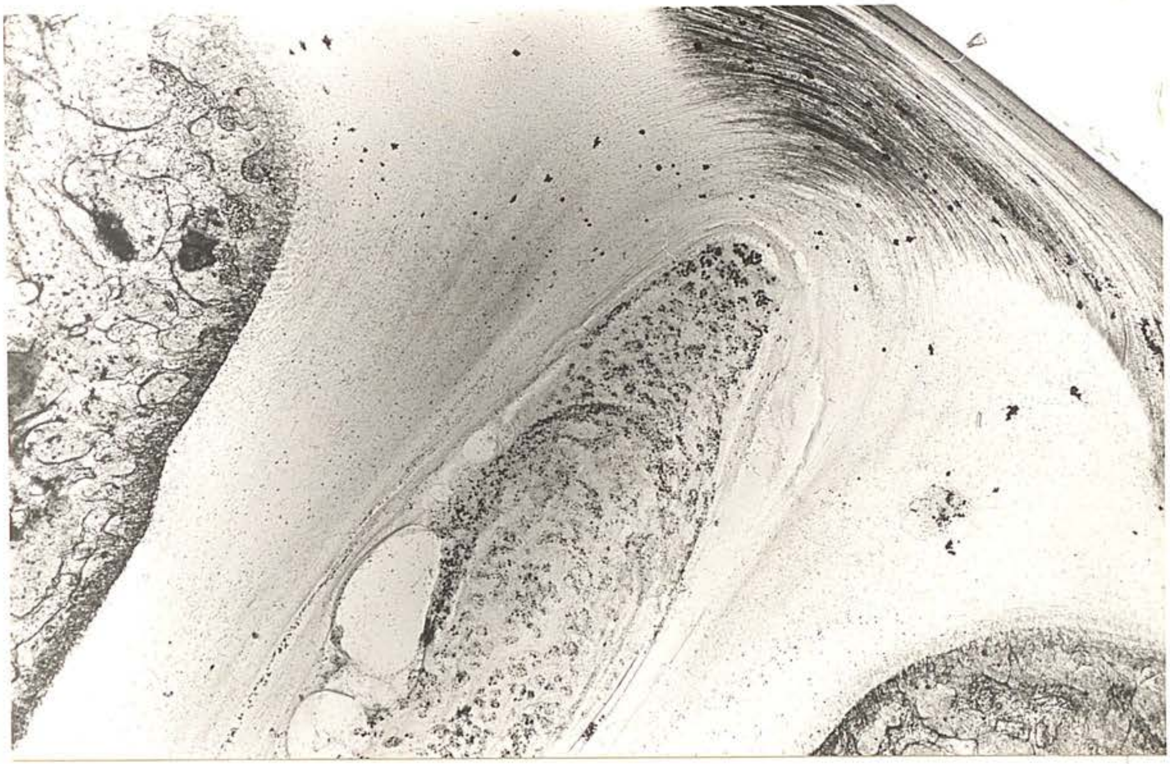
(a) L 4-5 disc, case no. 43 (5 month infant), sagittal section, x 20.

The posterior part of the disc: normal illumination.

(b) The same field, illuminated by polarised light, showing:

(i) the lamellar structure of the 'cartilage layers', and,

(ii) their continuity with the lamellae of the inner two thirds of the anulus fibrosus.

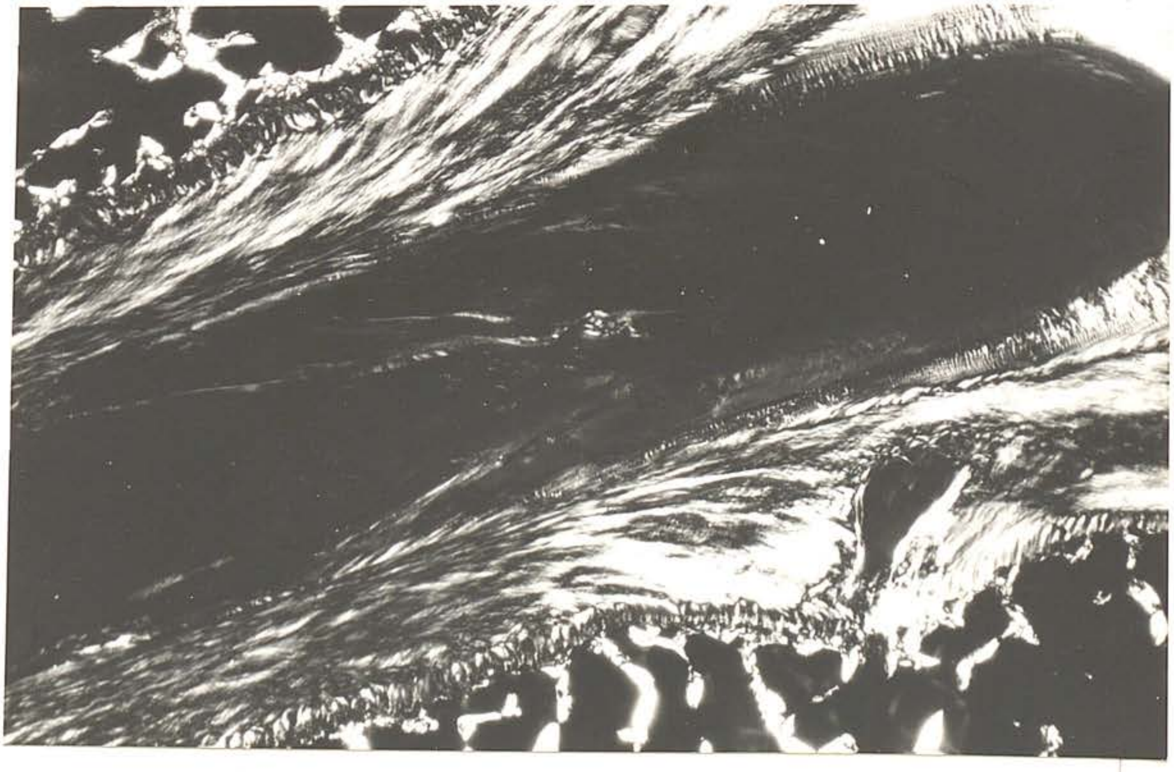


Text-fig. 84

Lamellae within the Notochordal Nucleus Pulposus of a two-year child

(a) L 4-5 disc, case No. 50 (2 years), sagittal section, x 20. The central and anterior parts of the notochordal nucleus pulposus,normal illumination.

(b) The same field, illuminated by polarised light, showing the presence of lamellar structures within the notochordal area, which were probably originally parts of the anulus fibrosus or 'cartilage layers'. The dark area in the lower cartilage plate is a cartilage canal, now avascular.



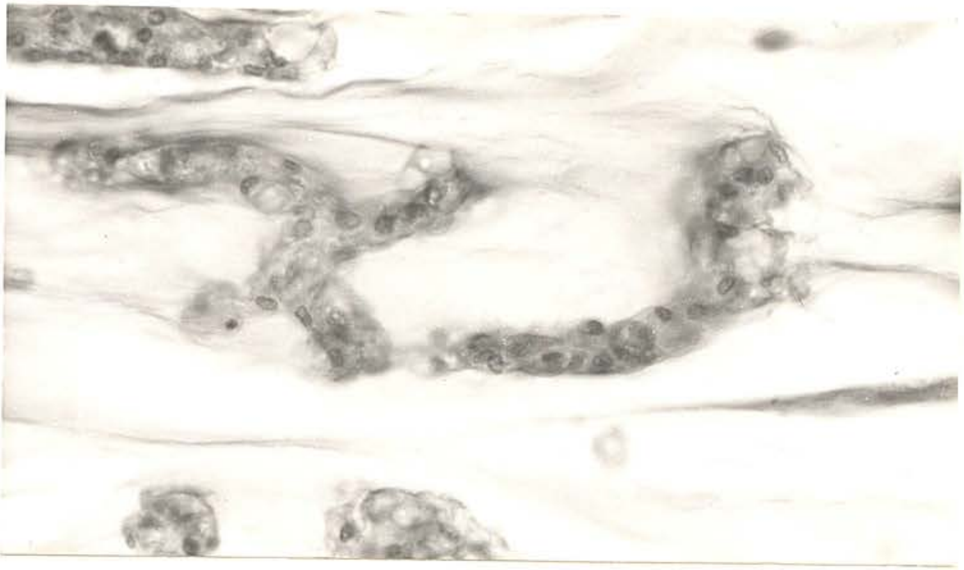
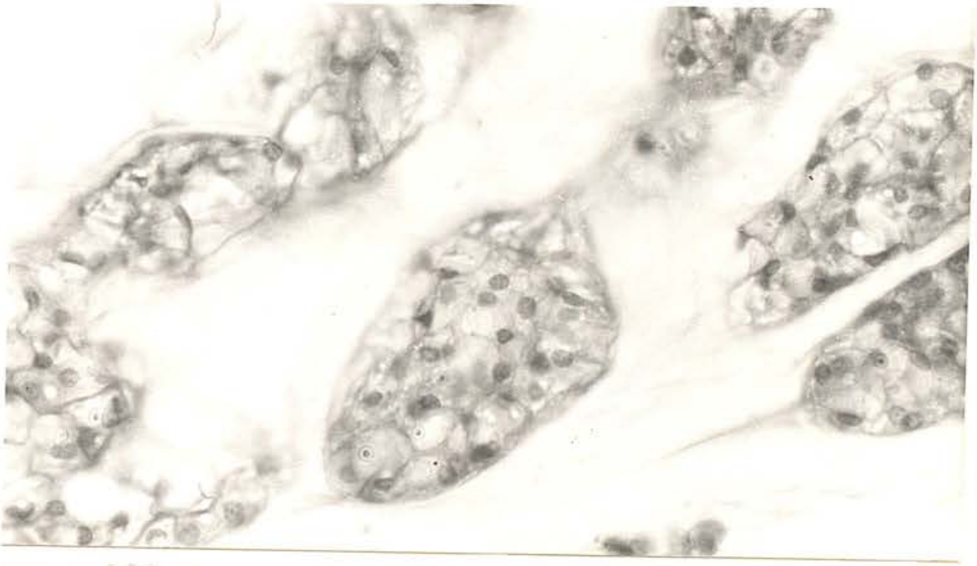
Text-fig. 85

Notochordal Cells

(a) Notochordal cells clumps in plentiful mucoid matrix x 480. 150 micron (L.V.N) sagittal section of a lumbar disc, case no. 17 (35 weeks) stained haematoxylin and light green.

(b) Notochordal cells in plentiful mucoid matrix x 480. 150 micron (L.V.N) sagittal section of a lumbar disc, case no. 27 (40 weeks) stained haematoxylin and light green.

(c) Notochordal cells forming a 'chorda reticulum' x 1200. 50 micron (L.V.N) sagittal section of a lumbar disc, case no. 41 (4 month infant) stained haematoxylin and light green.


Text-fig. 86

Notochordal Cells stained by Alcian Blue

Three illustrations of notochordal cells from the same section, at different magnifications.

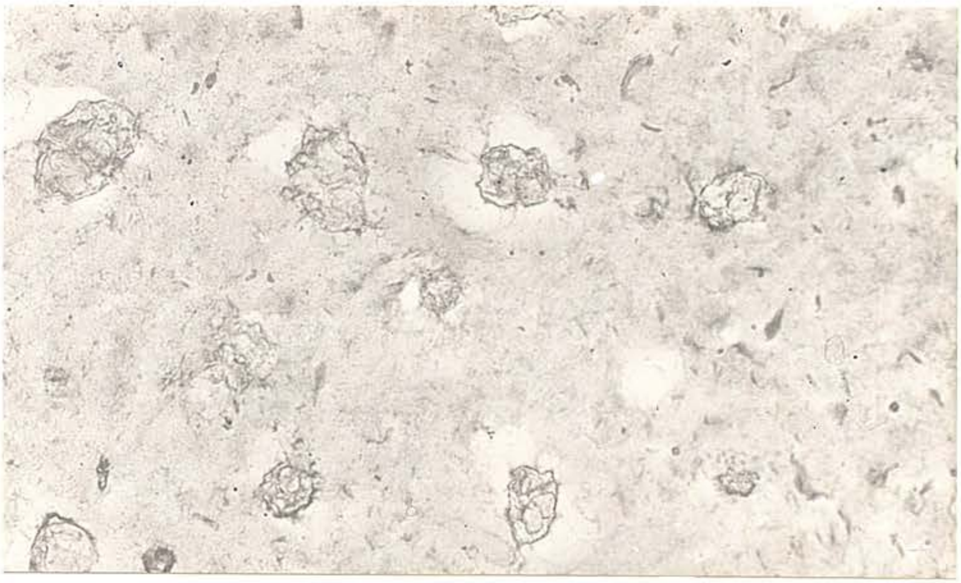
Lumbar disc, 10 micron wax section, stained by Alcian blue in 0.4 M. $Mg\ Cl_2$

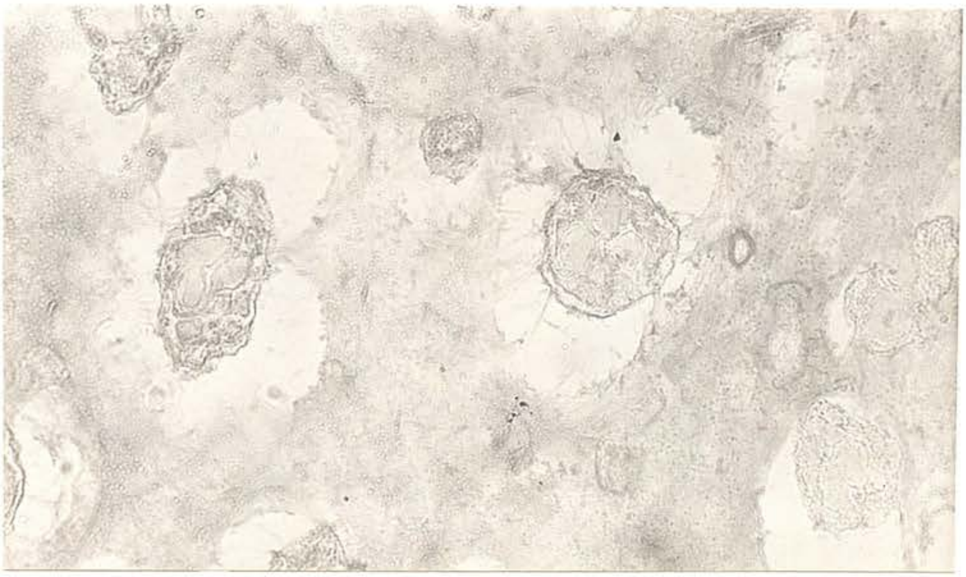
(a) Notochordal cell clumps in mucoid matrix, x 80.

(b) Notochordal cell clumps x 140.

(c) A notochordal cell clump x 350.

The cells themselves appear unstained, but they are ringed by the stain.





Text-fig. 87

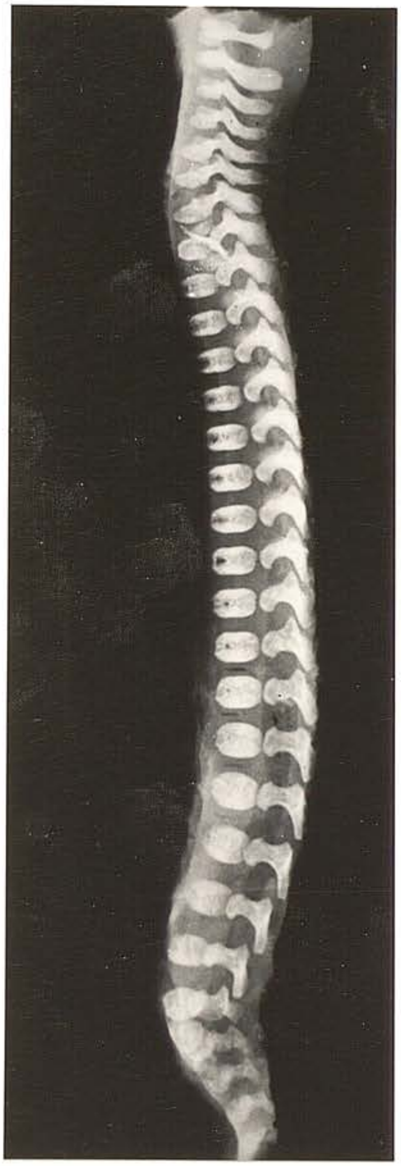
Lateral X-rays of the Vertebral Column

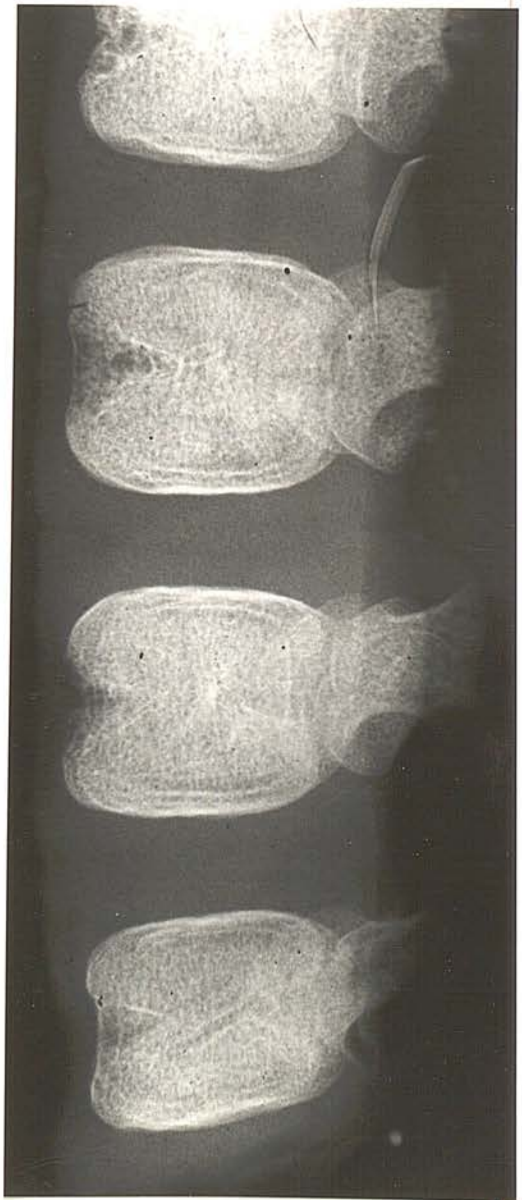
(a) Lateral X-ray of an excised vertebral column from a stillborn (36 week) foetus, x 0.7.

(b) Lateral X-ray of an excised lumbar vertebral column, case no. 44 (6 month infant) x 3.

Note: (i) that the vertebral end surfaces (of the centra) are convex.

(ii) growth arrest lines are visible in (b).





Text-fig. 88

Lateral X-rays of the Lumbar Vertebral Columns of Live Ambulant Children

(a) a four year child

x 0.8

(b) a four year child

x 0.9

(c) a seven year child

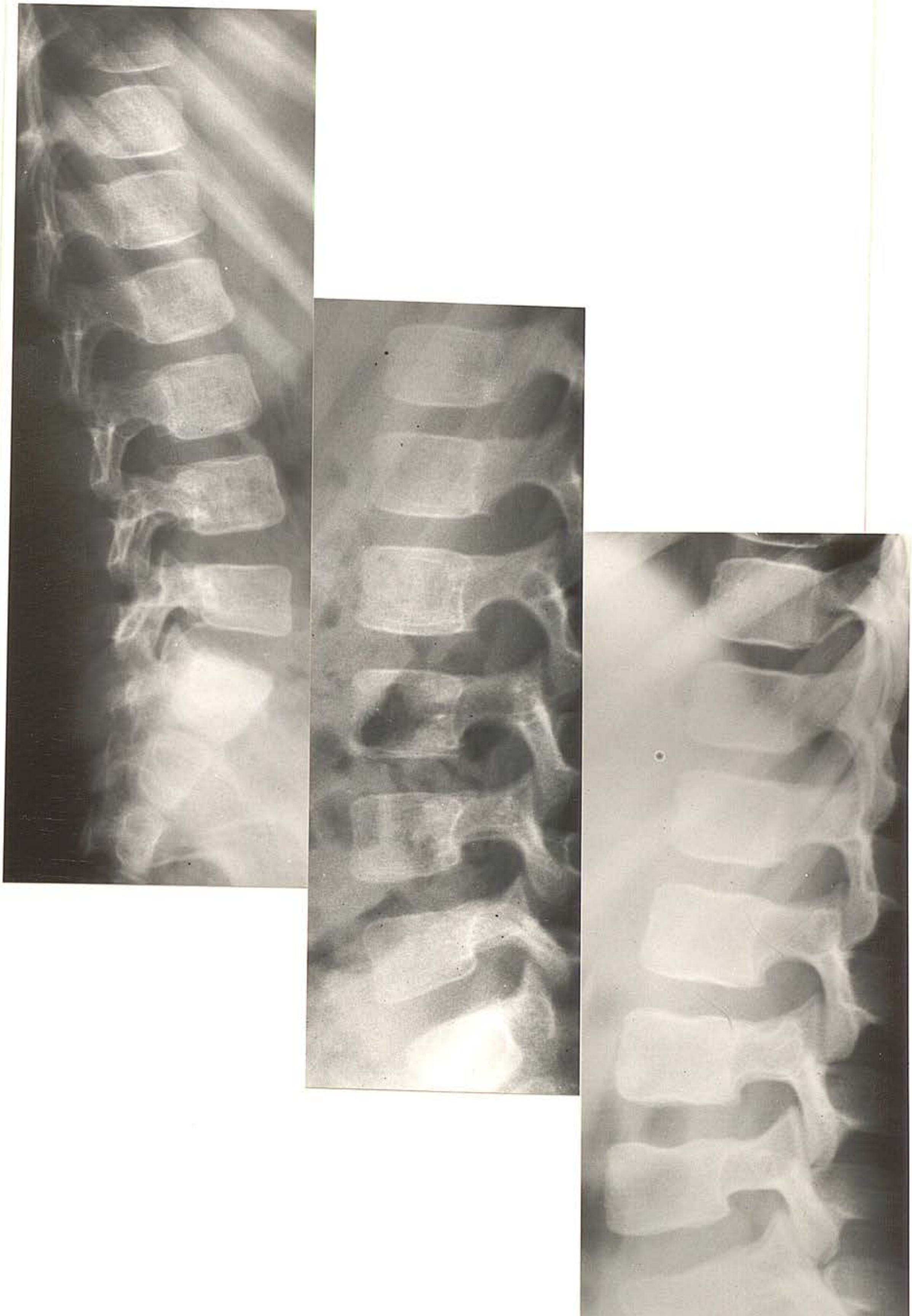
x 0.8

Note: (i) The cephalic and caudal end surfaces of the lower lumbar vertebral bodies are concave.

(ii) This concavity corresponds in (a) to the position of the maximum bulge of a typical notochordal nucleus pulposus (at three to five years), and may be responsible for the double lines for the vertebral end surfaces in L.4.

(iii) The concavity is more marked in (c) than in (a).

(iv) Growth arrest lines (b) are equidistant from the corresponding vertebral end-surfaces.



Text-fig. 89

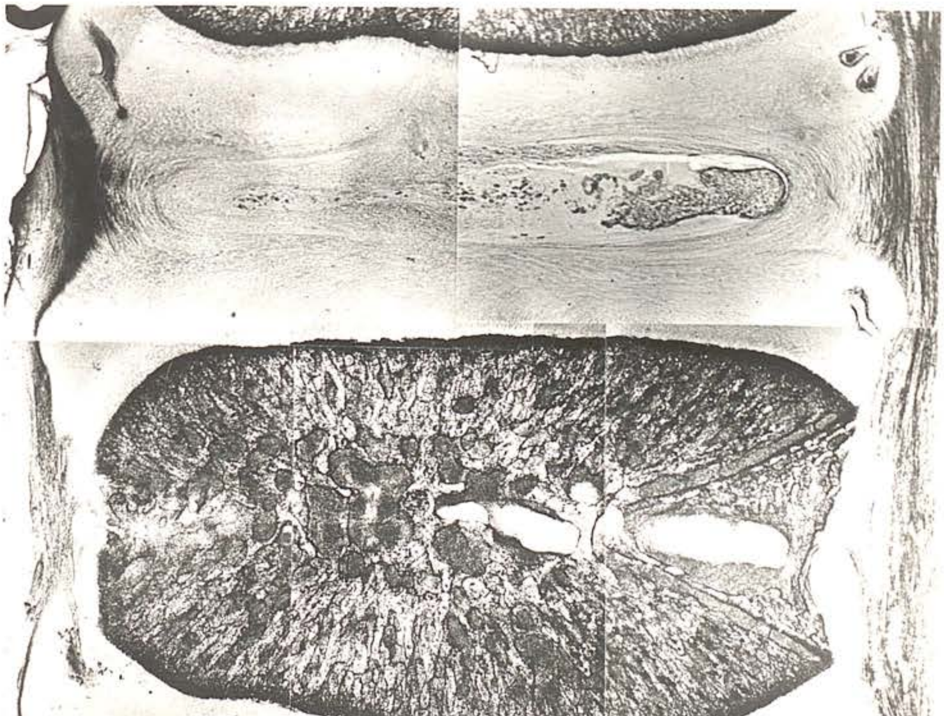
The 'Normal' appearance of 'Notochordal Defects' in 'Cartilage Layers' (see also Text-figs. 10 & 79(b))

(a) Median sagittal section of a cartilage plate and part of the notochordal nucleus pulposus from a 36 week foetus (case no. 19) L 4-5 disc, x 50.

Note: the funnel shaped defect in the 'cartilage layer', continuing as a cell free zone up to the edge of the growth plate.

(b) T 8-9 disc and T 9 vertebral body, case no. 22 (40 weeks) x 10. median sagittal section (anterior is to the left).

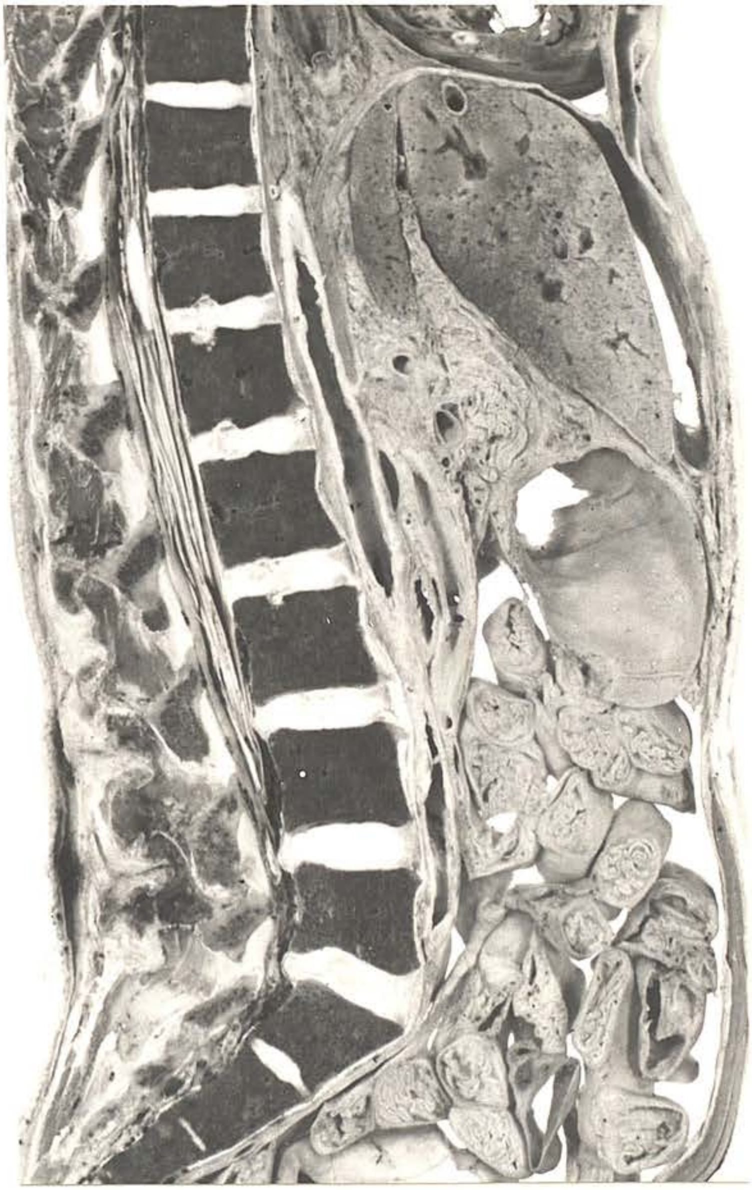
Note: the funnel shaped defect in the upper 'cartilage layer' (cf. Text-fig. 79 (b)) now separated from the posteriorly situated notochordal nucleus pulposus. At this defect, the thickness of the cartilage plate is considerably reduced.



Text-fig. 90

Multiple Schmorl's Nodes

Median sagittal section of the thoraco-lumbar vertebral column, showing Schmorl's nodes in T 12, L 1, L 2 and L 3. The nodes are vertically aligned in the median plane, suggesting a constantly situated weak point in the cartilage plates in this situation.



Text-fig. 91

Deformities of the Cartilage Plates and Vertebral End Surfaces

(a) Median sagittal section of the lumbar vertebral column, (x 0.7) showing multiple, vertically aligned angular depressions in the cartilage plates and vertebral end surfaces - L 1, L 2, L 3 and L 5. These may be regarded as incipient Schmorl's nodes.

(b) A higher power view (x 1.6) of L 4 and L 5

These deformities are suggestive of a constantly situated weak point in the cartilage plate or vertebral end surface, in the midline, nearer the posterior than the anterior surface of the vertebral bodies.

Text-fig. 92

Schmorl's Nodes in Median Sagittal Sections

(a) Schmorl's nodes in T 9 and T 10, seen in a midline section of a thoracic vertebral column, x 1.6.

(b) Schmorl's nodes in L 4 (the same case as (a) x 1.6


T8

E. THE BLOOD SUPPLY OF THE INTERVERTEBRAL DISC

1. The Anulus Fibrosus: Small blood vessesl are seen between the fibrous lamellae of the outer half of the anulus fibrosus at all stages of foetal life, infancy and childhood. The greatest density of blood vessels is found in foetuses (e.g. case No. 6 C - Text-figs. 98& 99). With increase in age the blood vessels become progressively less numerous between the collagen bundles as these increase in number and thickness.

2. The Cartilage Plates: Vascular canals are seen in the vertebrae from the 13th week (75 mm.) onwards in this series. In median sagittal sections of the thirteen week foetus the posterior surfaces of thoracic and lumbar vertebrae already show the deep "V" or concavity associated with the presence of the basivertebral vessels. Once the centrum extends to the circumference of its cartilage model, vascular canals are seen entering the cartilage plates cephalic and caudal to the centrum from subperiosteal vessels on the entire

circumference of the vertebra. Such vascular canals are numerous in the cartilage plates of foetuses and infants (Text-fig. 93).

The radially directed canals often enter the 'cartilage layer' directly, but may run tangential to the curved ossification front of the centrum, in contact with the bone for a short distance, before passing obliquely through the growth plate into the ' 'cartilage layer'. In addition to those canals entering from the circumference of the cartilage plate, a few canals appear to enter the 'cartilage layer' from the bone of the centrum, penetrating the growth plate at some distance from the circumference.

Within the 'cartilage layer' the canals give off branches towards the 'disc proper' and their vessels end in capillary tufts or 'glomeruli' (0.2 to 1.0 mm. in diameter) most of which reach to within 0.5 mm. of the interface between the 'cartilage layer' and the 'disc proper' (Text-fig. 96). They are distributed throughout the 'cartilage layer', ending in relation to both anulus fibrosus and nucleus pulposus, but are rather more numerous near the inner anulus and outer nucleus than elsewhere. Though the majority of canals and their branches (y and z, Text-fig. 13) end blindly within the 'cartilage layer', about a third of the canals (x, Text-fig. 13) entering from the circumference of the cartilage plate, after giving off branches towards the 'disc proper', loop back towards the centrum, penetrate the growth plate and end in a narrow blood space. Of canals entering the 'cartilage layer' from the centrum, some appear to pass through the centrum from sub-periosteal vessels and others appear simply as extensions of the marrow blood spaces through the growth plate. In the present study canals are classified and counted as described on page 64 and this descriptive analysis is shown in Table 22 and Text-fig. 13.

TABLE 22

Serial No.	Age	"Loops" (x)		Blind-ending Canals from periphery (y)		Blind-ending Canals from centrum (z)	
		No.	%	No.	%	No.	%
6	30w.	9	45%	9	45	2	12%
18	36w.	21	31%	39	58%	7	10%
38	2m.	10	30%	20	60%	5	10%
averages	-	40	33%	68	56%	14	11%

TABLE 23

VASCULARITY OF THE CARTILAGE LAYER RELATIVE TO THE 'DISC PROPER' VOLUME

Serial No.	Age	A No. of Canals and Major* Branches (containing blood vessels) within 1.2 mm. of the Disc Proper	B Volume of 'Disc Proper'	Vascularity A/B Index
4	29w.	122	0.16 ml.	763
6	30w.	123	0.22 ml.	559
22	40w.	240	0.64 ml.	375
23	40w.	246	0.60 ml.	410
42	4m.	226	1.10 ml.	205
46	14m.	206	2.74 ml.	75
55	3yr. 9m.	72	3.59 ml.	20
59	7yr. 6m.	60	5.33 ml.	11

* The canals were counted in sections at 1 mm. intervals in both cartilage layers bounding the disc proper.

The absolute number of canals increases up to full term, but the prenatal increase in 'disc proper' volume is relatively greater. Examination of sections from infants and children reveals not only a reduction in the number of canals with increase in age, but also a reduction in the size of the blood vessels seen in the canals. Thus the relative vascularity decreases progressively throughout. From infancy onwards an increasing number of 'canals' without blood vessels is seen. These are filled with a rather structureless loose deeply staining connective tissue. In some sections the 'cartilage layers' appear deformed in the region of blood vessels and the 'fibre pattern' of the cartilage layers may be evident in the deformed areas, though elsewhere it is only revealed by polarised light. These changes are thought to be contraction artefacts.

F. OBSERVATIONS ON CHORDOMATA

Sections from chordomata in various sites e.g. bone, muscle, glandular tissue, were observed by courtesy of Dr. A.F.J. Maloney of the Department of Neuropathology, at the Royal Infirmary of Edinburgh. Unfortunately no examples of chordoma in fibrous tissue, fibrocartilage or hyaline cartilage could be found.

The cells in a chordoma, although more pleomorphic than notochordal cells in developing intervertebral discs, closely resemble these notochordal cells. Tumour cells are seen in clumps, strands and often forming a reticulum. Their cytoplasm is eosinophilic and vacuolated and their nuclei are rounded, oval or irregular. Some of them show necrotic changes (faded nuclei and disintegrating cell boundaries) but much more extensive necrosis is seen in the surrounding tissues.

Many clear intercellular globules are seen and a clear mucoid matrix surrounds and separates the strands of cells. The peripheral parts of tumour masses infiltrate surrounding tissues in which necrotic changes are seen. A false capsule of tissue around some tumour masses resembles the foetal notochordal nucleus pulposus boundary in a number of ways e.g. there is necrosis in the layers nearest the chordoma cells, and parts of these layers of false capsule are observed 'peeling off' into the tumour mass.

Text-fig. 93

The Vascular Canals of the Cartilage Plates

Coronal sections of a 30 week foetal lumbar disc (case no. 6)

(a) L 4-5 disc, x 15.

A coronal section close to the anterior surface of the vertebral column. Vascular canals in the cartilage plates branch as they approach the anterior anulus fibrosus.

(b) The same disc, x 15.

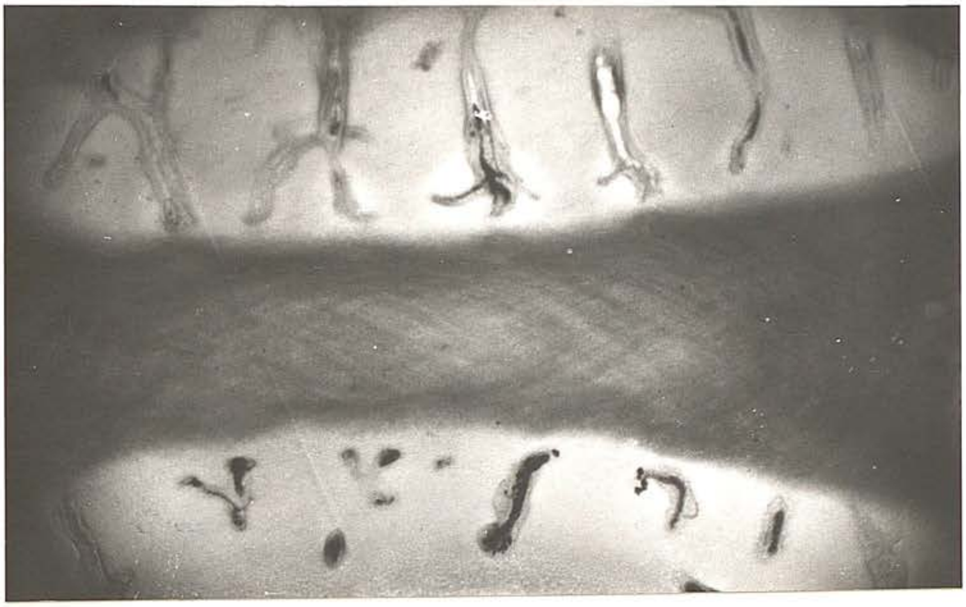
A coronal section further posteriorly. Vascular canals pass horizontally in a posterior direction, with branches towards the 'disc proper'.

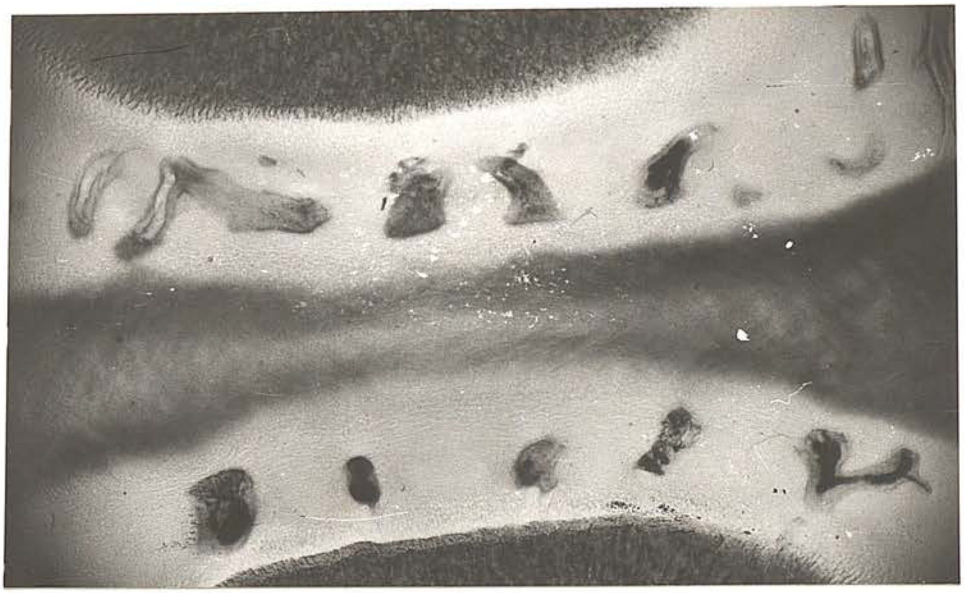
(c) The same disc, x 10.

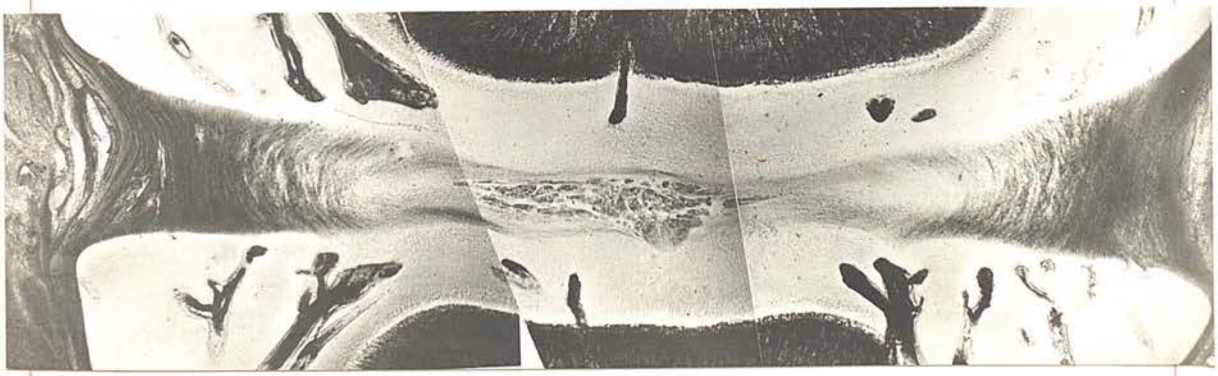
A coronal section midway between the anterior and posterior surfaces of the disc. Vascular canals approach the inner anulus and 'inner cell zone', with one canal in each cartilage plate approaching the nucleus pulposus from the vertebral centrum.

Figs. 93-102

Most canals arch radially from a sub-periosteal position towards the centre of the disc.







Text-fig. 94

Vascular Canals of the Cartilage Plates in Sagittal Section

showing 'loops' from sub-periosteal vessels to the vertebral marrow.

(a) L 4-5 disc, case no. 14 (34 weeks), x 20.

(b) L 4-5 disc, case no. 23 (40 weeks), x 24.

The vascular canals illustrated pass from sub-periosteal vessels, arch through the 'cartilage layer' giving branches towards the disc proper, and end in the vertebral marrow.

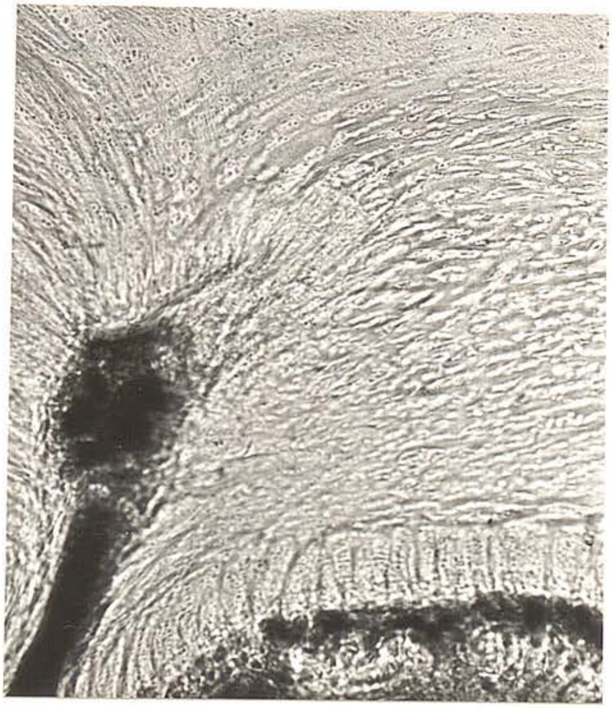
Text-fig. 95

Vascular Canals in the Cartilage Plates

(a) A lumbar disc, case no. 46 (14 month infant), x 30. Vascular canals shown in part of a sagittal section of a disc near the neuro-central joint. The canal at the left of the field lies on the ossification front, displacing the growth plate.

(b) A lumbar disc, case no. 46 (14 month infant), x 60.

A vascular canal in the 'cartilage layer'.



Text-fig. 96

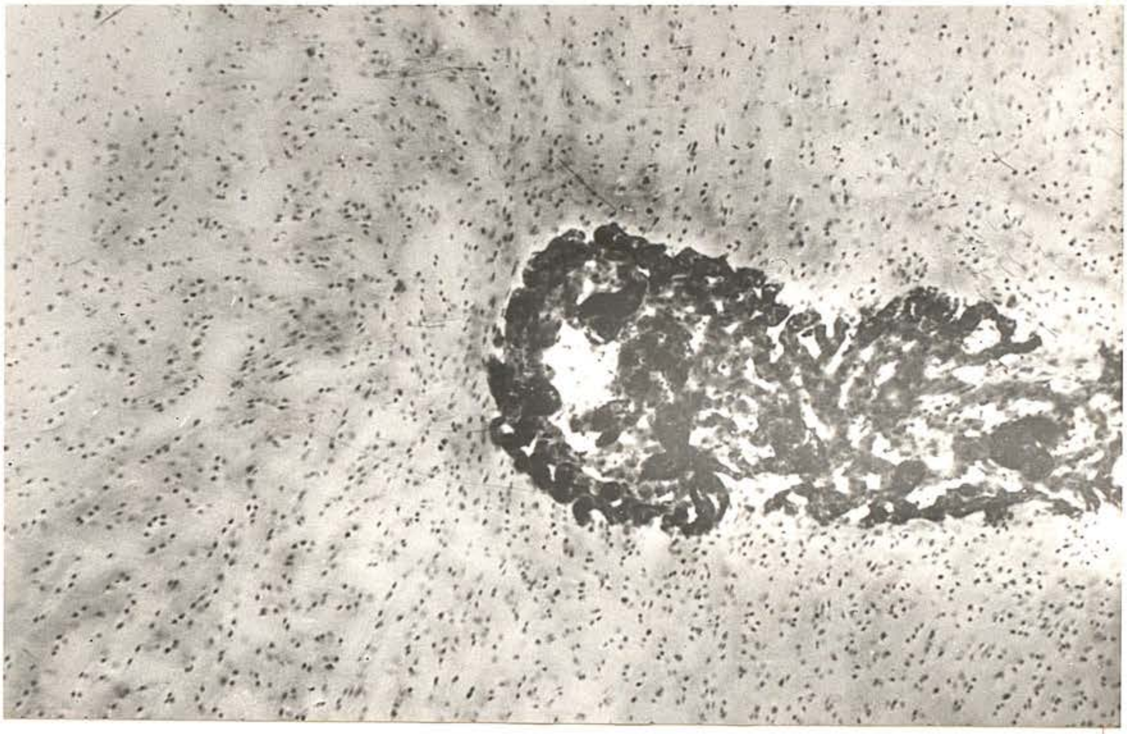
Capillary Networks in the 'Cartilage Layer'

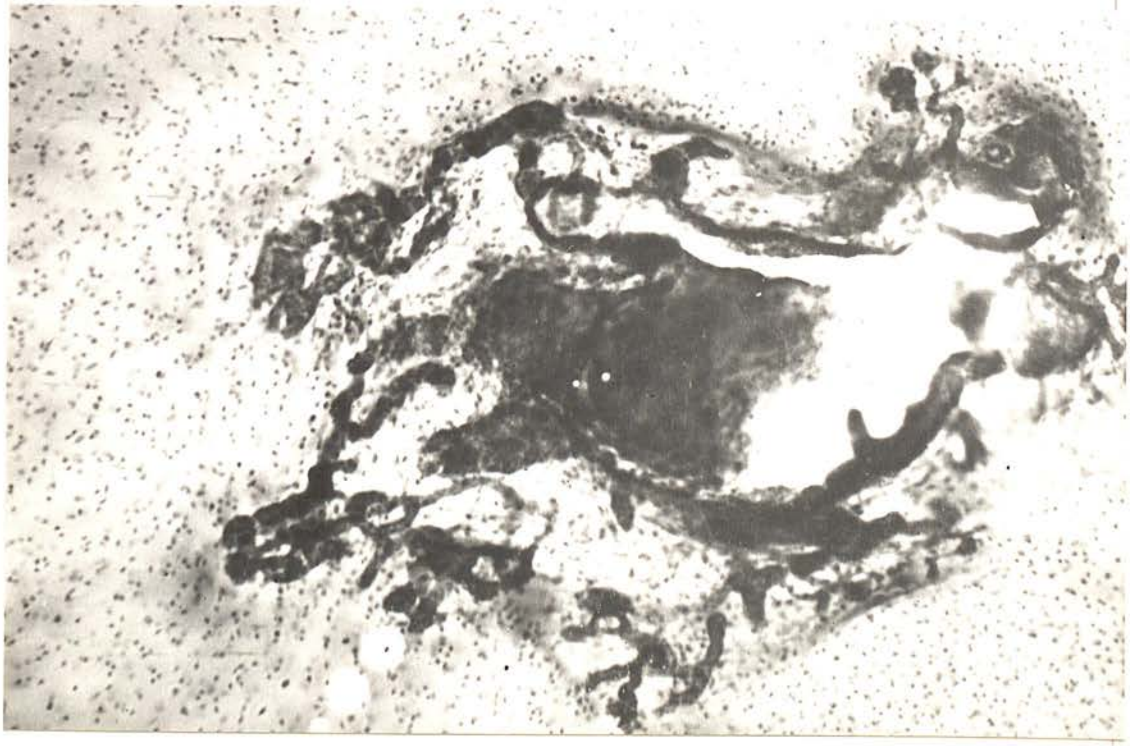
seen in coronal sections of a full term foetal lumbar disc

(a) L 3-4 disc, case no. 30 (40 weeks), x 120 stained haematoxylin, fuchsin and light green (erythrocytes are stained by the fuchsin).

The termination of a vascular canal forms a "glomerulus" of capillaries in the cartilage layer near the 'disc proper'.

(b) In the same section, a large vessel and capillaries around it are outlined by the stained erythrocytes they contain, (x 120).





Text-fig. 97

'Blind ending' - Vascular Canals appearing to originate from the Centrum

(a) L 3-4 disc, case no. 45 (10 month infant), x 24. Sagittal section of part of the central region of the disc. The canal shown appears to be an extension of a marrow space into the cartilage plate.

(b) L 4-5 disc, case no. 43 (5 month infant), x 75. Sagittal section of part of a cartilage plate showing an elongated vascular canal emerging into the cartilage plate from the centrum through an 'ossification gap'.

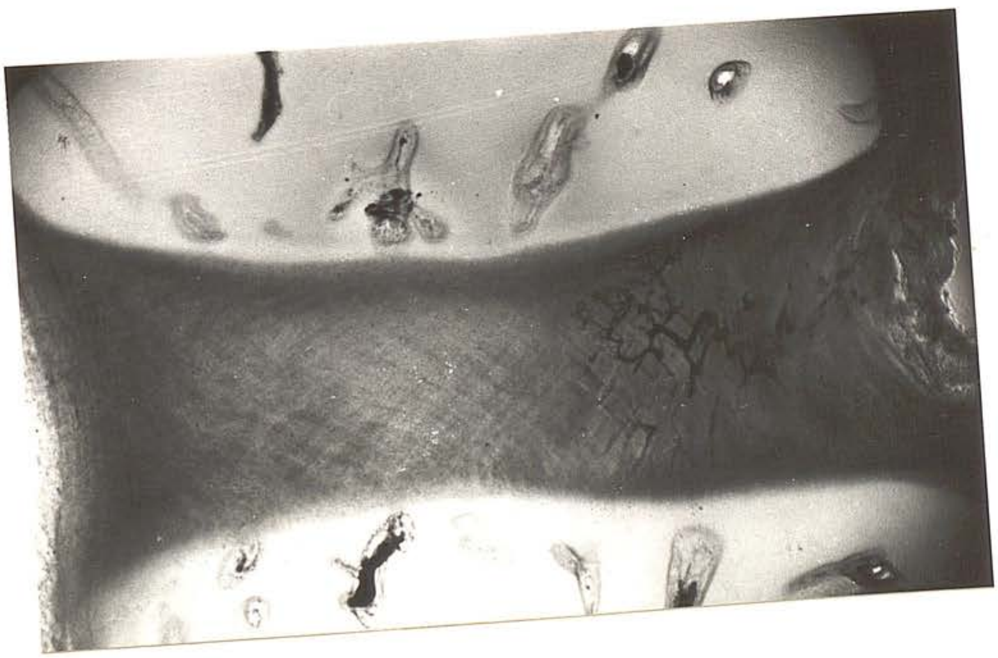

Text-fig. 98

Blood Vessels of the Anulus Fibrosus in Sagittal Sections

(posterior is to the right)

(a) L 3-4 disc, case no. 6 (30 week foetus), x 15. Sagittal section at about 2mm. depth from the lateral surface of the disc, showing branching vessels within the anulus fibrosus. The blood vessels appear to originate in the postero-lateral region of the disc.

(b) The same disc, a more medial section through the anulus fibrosus. More blood vessels are seen in the posterior part of the section, x 15.



Text-fig. 99

Blood Vessels of the Anulus Fibrosus in Sagittal Section

C 4-5 and C 5-6, case no. 6 (30 weeks), x 20. Rich vascular complexes are seen within the anulus fibrosus of each disc.

Text-fig. 100

Blood Vessels of the Anulus Fibrosus

(a) C 4-5 disc, case no. 6, a more medial sagittal section than that shown in Text-fig. 99, x 40. Blood vessels are very numerous.

(b) L 3-4 disc, case no. 16 (35 weeks), x 16. Horizontal section, showing the entry and branching of blood vessels in the postero-lateral region of the anulus fibrosus.

Text-fig. 101

Blood Vessels of the Intervertebral Discs of Children

(a) L 4-5 disc, case no. 50 (2 year child), x 20.
(stained haematoxylin and light green)

Sagittal section of a cartilage plate, showing a cartilage canal which is avascular, and filled by a loose, somewhat hyaline, pink staining connective tissue.

A similar avascular cartilage canal is illustrated in Text-fig. 84.

(b) L 4-5 disc, case no. 55 (3yr. 9m.), x 120.

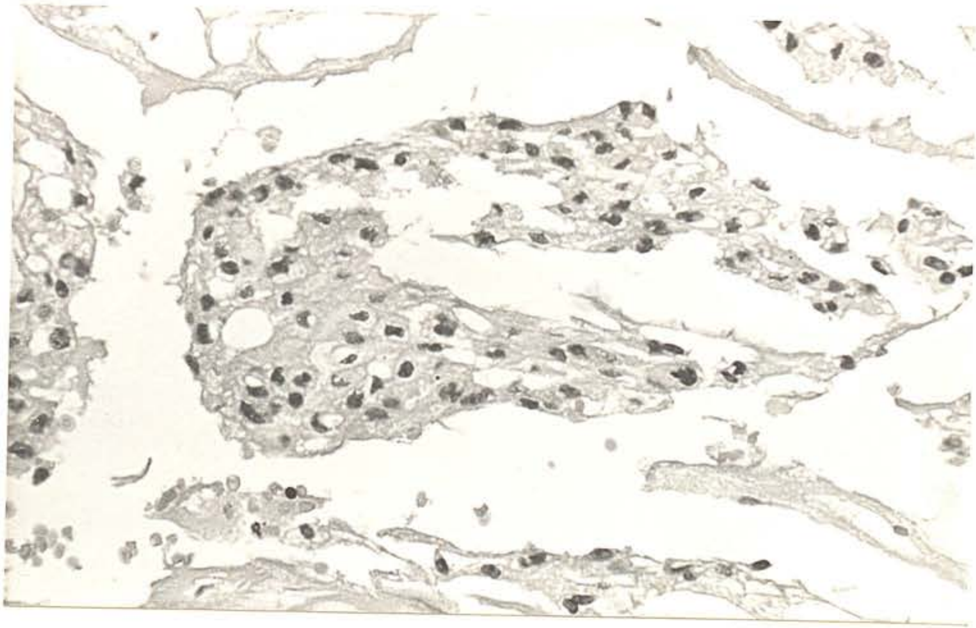
Blood vessels in the outer anulus fibrosus, seen in a sagittal section. (The anterior surface of the disc is at the lower margin of the illustration).

Text-fig. 102

Chordoma

(a) A secondary tumour in muscle with a false capsule around it. 10 micron section, H. & E., x 20.

(b) Notochordal cells from the above tumuour mass. 10 micron section, H. & E., x 350.



DISCUSSION

A. MATERIAL REQUIRED FOR STUDY OF GROWTH

1. Absolute Growth

Ideally, longitudinal data from a number of individuals would be used to study growth. No such data is available. The cross-sectional postmortem data in this study is obtained from 67 cases collected over three to four years. With the exception of Böhmig's (1930) series, no series of foetuses, infants and children of comparable size could be found in the literature. Böhmig did not use his material for a quantitative study of growth (since 1930 still-births, infant and child mortality rates have all been markedly reduced and the availability of material has lessened in consequence). To establish means for the dimensions of vertebrae and discs which approximate with reasonable certainty to those of the general population at the same age, a larger number of cases is necessary than those obtained at postmortem for this study. For this reason dimensions of 'total disc' height and 'vertebral body' height were also measured on radiographs of a large number of normal vertebral columns. Though many of the dimensions recorded in this study can only be measured on postmortem material e.g. 'Disc proper' and cartilage plate thickness, the large number of radiographic measurements on discs and vertebrae help to confirm that the figures obtained from postmortem material fall into the same general range and that the postmortem cases are not therefore an abnormal sample. (But the two types of measurements are not strictly comparable - see below).

2. Relative growth

When relatively few cases are available from which to record the dimensions, comparison of absolute dimensions at different ages would be fallacious if some of the individuals measured were smaller or larger than the average for their age. However, it is possible to minimise the problem of variation in size at a given age by studying growth of one part relative to another e.g. by the use of indices such as $\frac{\text{disc thickness}}{\text{vertebral height}}$ at different ages.

Many authors have studied allometric rather than absolute growth (Zuckerman 1950), and some use this method to study vertebral growth (Aeby, 1879; Lippert & Lippert, 1960; Hipps, 1961; Rabinowitz & Moseley, 1964; Houston & Zaleski, 1967; Brandner, 1970). Taylor, 1970 and Brandner, 1970 study the relative growth of inter-vertebral discs using the index disc height/vertebral body height. Schmorl & Junghanns' (1959) observe that the proportion of disc thickness to adjacent vertebral height changes from a 1 / 1 relationship in a new-born infant to a one to two ratio in a four year child and finally to a one to three ratio in the adult.

Ballantyne (1892) ascribes the relative flexibility of the foetal spine to the relatively high disc height/vertebral height ratio, and a number of authors, inter alia Geist (1931), Schmorl & Junghanns (1959), Katz (1961) and Brandner (1970) refer to the more rapid relative growth in height of the vertebral body postnatally.

B. AN EVALUATION OF THE DATA OBTAINED FROM X-RAY AND POST-MORTEM MEASUREMENTS

1. Comparability of X-ray and Postmortem Measurement

When this study was undertaken the view was held that vertical measurements on discs and vertebrae made as described using radiographs and sections and suitably corrected for magnification error or contraction artefact, would be comparable. However, the results from the two sources (Table 8a), page 92 , and Text-figs. 28 & 30. suggest that they are not strictly comparable. This is particularly noticable in the L 4-5 disc where the postmortem means are consistently greater than the X-ray means in infancy and the growth curve constructed from postmortem means from two to seven years is steeper than that constructed from X-ray means.

Further examination of the sections and of a number of X-rays at different ages suggests that the reasons for these differences may be as follows.

(a) There is a relative inaccuracy in all X-ray measurements. The boundaries of the vertebral centra are less sharp than in the sections of postmortem material so that the points from which measurements are made cannot be so accurately defined and depend on a subjective judgement on X-rays of variable quality.

(b) Underestimation of the 'total disc' in X-rays of infants. It is more difficult to obtain true lateral radiographs of infant vertebral columns and minor degrees of obliquity of the X-ray beam lead to underestimation of the 'disc space' and overestimation of the height of the centrum. Comparison of mean values for 'total disc' and 'vertebral body' in X-ray and postmortem groups at forty weeks (Table 8, page 92) tends to confirm this.

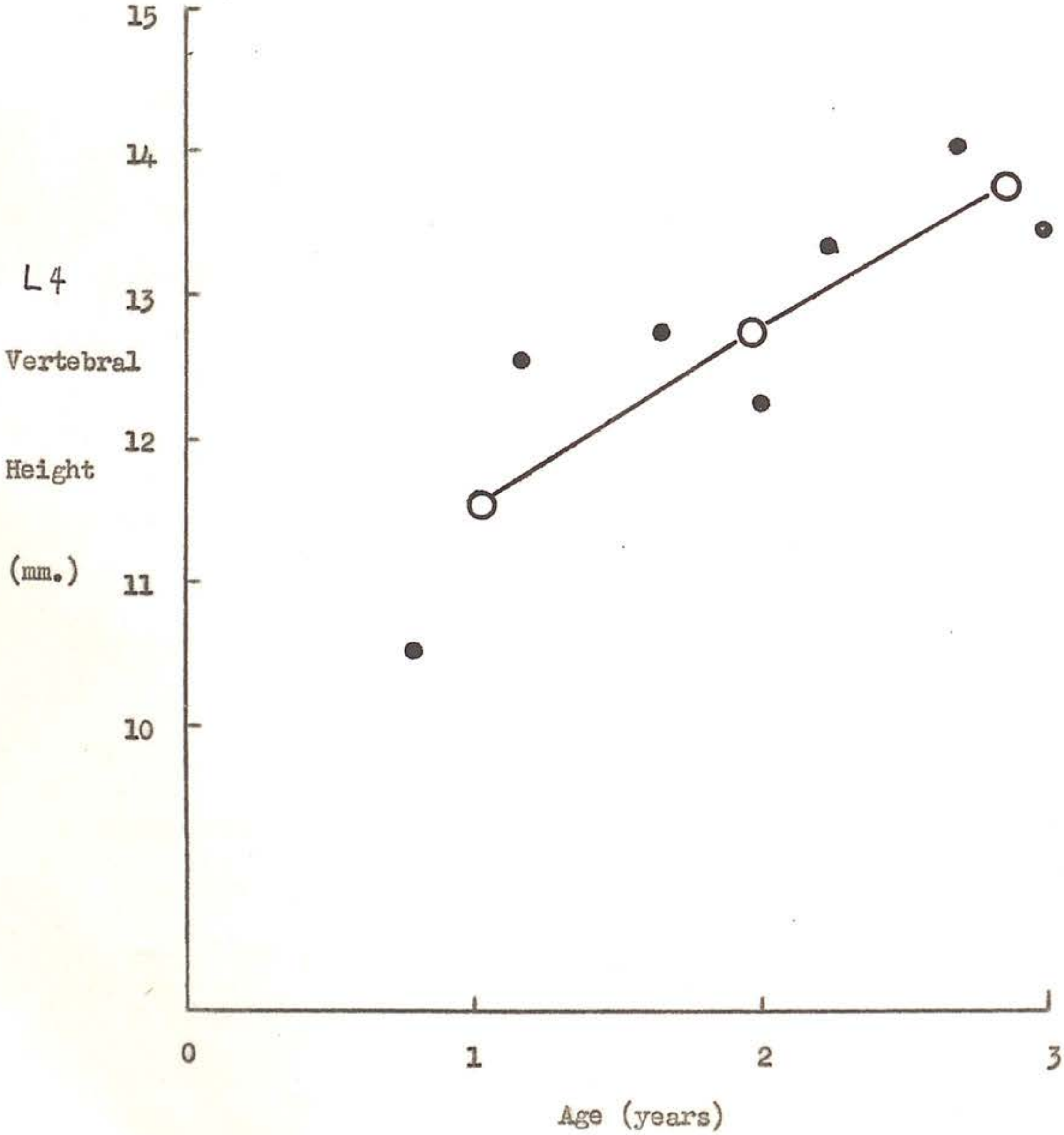
(c) Variation in X-ray measurement error due to change in vertebral shape. The flatter slope through X-ray mean values (for the L 4-5 disc) from two to seven years could be accounted for by a relative overestimation of the 'disc space' or 'total disc' in two year old children who have vertebral bodies convex towards the disc, and under-estimation of the 'total disc' in five and six year olds who have concave vertebral end surfaces. In two year olds, points between which the 'total disc' is measured in median sagittal sections coincide with the summits of the convexities of the bony vertebral bodies. A lateral radiograph of the vertebral column corresponds to a superimposition of a number of parasagittal sections. Hence in radiographs one is liable to measure between the 'average' of a number of 'summits of convexities', thereby giving an overestimate of the 'total disc'. Similarly, when the vertebral end surfaces are concave, the measurement made in a mid-line sagittal section is approximately between the points of maximum concavity, while the radiograph gives a superimposition of all sagittal sections near the midline, thus underestimating the true mid-line 'total disc'.

This error would apply particularly to the disc L 4-5 as changes in shape of the vertebrae bounding the 'total disc' T 8-9 are slight. Thoracic vertebral end-surfaces are fairly flat at all stages from two to seven years, but a slight concavity may be found in the vertebral end surface of some children - usually nearer the posterior surfaces of the vertebral bodies and discs. There are only five 'total disc' measurements on thoracic postmortem cases between two and seven years, and it is uncertain whether the lower means for X-ray data in this age range represent an underestimate of the disc space or not. (Text-fig. 30).

2. Comparability of Different Age Groups in the Postmortem Series

(a) The two year old group of postmortem cases could be "small for their age". However the causes of death shown for cases Nos. 48 to 51 are no more likely to be correlated with smallness of stature than the similar spectrum of causes of death shown for the other cases in the postmortem series. Only the foetuses and infants were weighed at autopsy, but the pathologist's reports give a description of the external features of the children and of their state of development if this is abnormal, e.g. No. 47 (18m.) is described as physically retarded (this case was not included in the study of growth). Of the cases in question, Nos. 48 and 51 are described as "well nourished" No. 50 as "normally developed for the age of two years", but no comment about No.49 is made. Descriptions of nutrition and development are in similar terms for cases Nos. 45 (10m.), 46 (14m.), 52 (2yrs. 8m.), 54 (3yrs. 4m.), and 55 (3yrs.9m.). Most values for the two year group (e.g. 'total disc', cartilage plate thickness, cross-sectional area and volume of the notochordal nucleus pulposus, (Text-figs. 27, 33&42) appear low for their age compared to the one year and three year groups. The lateral horizontal diameter is an exception to this trend (Text-fig. 38). Nevertheless, the recorded observations of an experienced paediatric pathologist suggest that the group at two years is normal as regards nutrition and development, and is at least comparable in these respects to the groups at one year and three years.

Text-fig. 103



The 'vertebral body' heights recorded for Nos. 48 and 49 are lower than the mean value for X-ray cases at two years, but (comparing postmortem cases with one another) the mean value for 'vertebral body' height at two years (cases Nos. 48, 49 and 51) is 'in line' with the means for one year (Nos. 45 and 46) and three years (Nos. 52 and 53) in the graph of 'vertebral body' height (Text-fig. 103). It is possible that a number of postnatal cases in the post-mortem series are 'small for their age' compared with X-ray cases of similar age, due to the more serious nature of the illness in some of the postmortem series (e.g. congenital heart disease, biliary atresia), but the one year, two year and three year groups are equally subject to similar influences and they form a valid developmental series.

(b) There may be variation in contraction artefact of the disc at different ages, particularly in the notochordal nucleus, if the water content is higher at one age than at another. There is no evidence, however, that the two year old disc is more hydrated than the one year old disc. On the contrary, Puschel (1930) finds that the percentage water content of both anulus and nucleus are highest in the newborn, gradually decreasing with increasing age. She records the water content in grams per 100 grams of lumbar intervertebral disc substance as follows -

	Nucleus	Anulus
foetuses:	89% and 88.2%	78.1% & 78.2%
7 months:	84.4%	76.6%
11 months:	85.0%	75.5%
$2\frac{1}{2}$ years:	82.9%	74.0%
7 years:	81.5%	72.9%

In the present study, histological observation and measurement suggest that the notochordal nucleus forms a higher percentage of the cross-sectional area of the disc at one year and three years than at two years. Its matrix has a broadly similar appearance at all three stages though there is some increase in the collagen fibre content with increase in age. The only measurement of contraction artefact made on a two year case (No.51) gives a linear contraction of 7% compared with the average linear contraction of 6%, an insignificant difference.

(c) <u>Changes in growth rate may be masked by biological variation in cross-sectional data</u>, particularly where means are calculated from groups including a relatively wide age range. It is well known that at adolescence, averaging of a large number of height measurements (cross-sectional data) masks the peak of growth velocity revealed by a longitudinal study of growth at adolescence (Israelson, 1960). Similarly, in the present study, any 'dip' in the L 4-5 'total disc' growth curve at two years would be obscured by averaging the large number of measurements from individuals in whom there is variation in the timing of any change in the rate of vertical growth. It also happens that the postmortem cases in group 6, Table 8(a) fall within a narrower age range than the group as a whole. Variation in size would therefore tend to be less in the postmortem cases. Division of the X-ray data from the two year group (Table 8(a), group 6) into three sub-groups reveals a greater fall in the 'total disc'/vertebral body, index at 1 year 9 months than in the 2 year group (x-ray cases only) as a whole and suggests that any dip in 'total disc' growth may occur at an earlier age in the x-ray cases than in the postmortem group.

C. VERTICAL GROWTH

1. Vertebra

The bony vertebral body grows in height at its cranial and caudal metaphyses (Bardeen, 1905; Harris, 1933; Haas, 1939; Bick and Copel, 1950). Moser (1960) measures vertebral growth in pigs following selective X-irradiation injury to upper or lower growth plates and claims that growth in the cephalic growth plate is more rapid than growth in the caudal growth plate. Moser (1970) describes a similar pattern in human vertebral growth, since he finds cartilage columns in the cranial growth plates of children "substantially higher" than those in the caudal growth plates. Harrison (1958) and Keegan & Harrison (1961) on the other hand claim that vertebrae in the rat grow more rapidly at the caudal than at the cranial growth plate. Bisgard and Musselman (1940) implant steel shot in the lumbar vertebral bodies of immature goats and find equal growth increments in cranial and caudal directions one month and ten months later. Bateman (1954) finds that mouse vertebrae grow at about equal rates at each end. Knutsson (1961) claims that at all stages the cranial and caudal surfaces of the human vertebral body can be seen to be equidistant from its equator, where the central vascular marking is still visible. He also illustrates radiographs of growth arrest lines equidistant from cranial and caudal vertebral surfaces in support of his view that growth at the cranial and caudal ends are equal. Siegling (1941), Schinz (1952), Larsen & Nordentoft (1962), Gooding & Neuhauser (1965), O'Brien (1969) and Katzman (1969) also publish illustrations of radiographs of the 'bone within a bone' appearance of growth arrest lines in vertebral bodies. Although these show unequal growth in the sagittal plane, in each case the lines are equidistant from the corresponding end surfaces. In a few radiographs examined during the present study 'growth lines' are seen in thoracic or lumbar vertebral bodies. These are always equidistant from their respective end plates.

Measurements of the heights of the cartilage columns at the cranial and caudal ends of the same lumbar vertebral body in a number of cases from the present series (Table 9(e)) find the cartilage columns of the caudal growth plates in foetuses to be significantly taller than the corresponding cranial cartilage columns. In lumbar vertebrae of infants and children, the situation is reversed, the cranial cartilage column height exceeding the caudal cartilage column height.

The apparent contradictions in the observations of Bisgard & Musselman (1940), Moser (1960), and Keegan & Harrison (1961) may be due to species differences, or to different patterns of growth in different regions of the vertebral column, but could be due to different patterns of growth at different stages of development.

The present observations show that cartilage columns tend to become shorter as age increases and as growth decreases. They also confirm the observation of Moser (1960) that cranial growth plates are thicker than the corresponding caudal growth plates in children, but cannot confirm Moser's conclusion that cranial growth exceeds caudal growth in children's vertebral bodies. Radiological evidence suggests that postnatal growth of the human vertebral body is approximately equal at its cranial and caudal ends.

In the present study, growth graphs for L4, T8 and C5 follow smooth curves (except for a slight depression in the growth curve for L 4 at age 7 years). Any change in the pattern of vertical disc growth is therefore in contrast with this smooth pattern of vertebral growth. The only sex difference found by comparison of male and female growth curves for the same three vertebrae is the greater height in female vertebral bodies from nine to thirteen and a half years (Text-fig. 24).

2. <u>Intervertebral Disc</u>

Measurements of the absolute heights of growing discs are notably absent from published literature, though Aeby (1879) records external measurements of discs from a few individuals between birth and adult life.

Schmorl & Junghanns (1959) give the approximate ratio for the disc ('total disc') to the adjacent vertebra at birth, at four years and in adults (as seen in radiographs). Many standard anatomical texts (e.g. Cunningham, 1972) refer to the proportion of the pre-sacral vertebral column length produced by the 'discs'. Brandner (1970) studies disc growth ('total disc') relative to vertebral body growth using data obtained from lateral radiographs of immature vertebral columns.

(a) <u>The 'Total Disc'</u>. While the disc, as defined in most standard texts, excludes the cartilage plates, the 'disc' measured by Schmorl & Junghanns (1959) and Brandner (1970) includes the cartilage plates. (This controversy is briefly reviewed in the introduction pp.6 & 27). In radiographs the only measurable disc is the 'total disc'.

Study of the 'total disc' growth either alone or relative to bony vertebral body growth may be criticised on the grounds that the 'total disc' is a composite structure, including the intervertebral disc as defined anatomically (referred to here as 'disc proper') with the cartilage plates regarded by many as parts of the vertebral body. (see page 27). (The Nomina Anatomica avoids the issue by not including the cartilage plates in any section.) Schmorl & Junghanns (1959) regard the 'total discs' (as defined here) as "mobile elastic stress-bearing .... units in contradistinction to the rigid intervening vertebral bodies". Schmorl & Junghanns (1959) associate the cartilage plate with the 'disc' for the further reason that "they originate developmentally from the same tissue, and even after development is complete, remain closely related ... joined by the gradual transition of one tissue into another". The anlagen of the cartilage plates and of the 'disc proper' are identifiable in the 12 mm. embryo as separate parts of the perichordal disc (Wyburn, 1944).

It is suggested that the controversy regarding the inclusion of the cartilage plates with either the intervertebral disc or the vertebral body results from (a) an oversimplified view of the cartilage plate as one homogeneous structure and (b) a mistaken belief that they must 'belong' to <u>either</u> the vertebra <u>or</u> the disc as if these were strictly separate entities. As suggested in the introductory review, (p.28) the immature cartilage plate may be regarded as consisting of (i) a growth plate - contributing to bony vertebral growth, applied to the cephalic and caudal ossification fronts of the vertebral body, and (ii) a layer of hyaline cartilage lying between the growth plate and the 'disc proper' in which polarised light studies reveal a continuation of the lamellar system of the anulus fibrosus (Franceschini, 1947). In the horizontal periphery of this hyaline 'cartilage layer' a bony rim will develop before puberty to fuse with the vertebral body in early adult life. The central part of this 'layer' remains permanently cartilaginous (bounding the disc proper), (Schmorl & Junghanns, 1959).

It is held here that the anulus fibrosus as defined in standard anatomical texts is incomplete (Text-fig.83) and that the anatomical textbook convention of regarding the cartilage plate as part of the vertebral body is an artificial one not in accord with its function and only partly in accord with its development and morphology.

The growth plate is part of the vertebral body since it contributes to its growth and eventually ossifies. The hyaline 'cartilage layer' though indistinguishable from the 'cartilage model' of the developing vertebral body by ordinary light microscopy, is comparable to articular cartilage (McKibbin & Holdsworth, 1967) in that it never ossifies. It contains part of the fibrous envelope which encloses the nucleus pulposus, said to 'undergo liquefactive changes' where it bounds the notochordal nucleus pulposus, its substance contributing to the growth in volume of the nucleus (Peacock 1951). It should be regarded therefore as common to both the vertebral body and the intervertebral disc, an area in which the two structures overlap.

It is conceded that the 'total disc' is a composite structure in the sense that it is not homogeneous, but similar considerations apply to the anatomical 'disc proper'. It is considered as legitimate to measure the 'total disc' as to measure the 'disc proper' and in radiographs the height of the former can be measured, and compared to the height of the adjacent centrum, while the anatomical disc height cannot be measured in ordinary radiographs. It is recognised that vertical growth of the bony vertebra is probably a simple matter of apposition of bone at its cephalic and caudal surfaces (Harris, 1933) while change in the vertical dimensions of the 'total disc' are more complex. For this reason, in addition to the 'total disc', its separate parts viz. growth plates, hyaline 'cartilage layers' and 'disc proper' are measured in sectioned material in this study.

(b) <u>Vertical Growth of the 'Total Disc'</u> In his studies on the ratio Disc Height/Vertebral Height in infants and children, Brandner (1970) demonstrates a significant reduction in the ratio or index ('I-d') during infancy but is unable to show any other significant change in the ratio. He does not record absolute values for either disc or vertebral height, but gives the 'mean index' for five age groups (based on measurements of 187 radiographs of subjects from birth to adolescence).

The present work not only demonstrates changes in vertical dimensions of the 'total disc' but also records changes in the disc height/vertebral height index from foetal life to adult life for C 5-6/C5, T 8-9/T8 and L 4-5/L 4 (Text-fig. 32 and Table 8).

During foetal life and infancy the pattern of change in Total Disc/Vertebral body (T.D./V.B.) index is similar for L 4-5, T 8-9, and C 5-6. The decrease is statistically significant between each successive group, e.g. for the four stages: 32 weeks, 40 weeks, $3\frac{1}{2}$ months and 9 months in the case of L 4-5/L 4 (Table 8(a) page 93). This result agrees with Brandner's (1970) work, but it covers a wider range including the second half of intra-uterine life in addition to the first year of life. Thus throughout foetal life in infancy, the centrum increases in height more rapidly than the 'total disc' in all three regions measured. After infancy, the changes in

L 4-5/L 4 contrast with those for T 8-9/T 8 and C 5-6/C 5, particularly in the period from two to four years when L 4-5/L 4 index shows a significant increase (Table 8(a) page93) and the growth increments for L 4-5 exceed those for L 4, while the thoracic and cervical indices appear to continue their downward trend (Text-fig.32) The relative increase in growth rate for L 4-5 during the period two to four years (as shown by the index L 4-5/L 4) is found in both sexes and in material from X-ray and post-mortem sources.

Brandner (1970) did not describe any increase in his index "I-d" during childhood. He reports a downward trend in the index "I-d" for discs T 11-12 to L 2-3 inclusive. Though Brandner's data for T 11-12 and T 12-L 1 show a continuous downward trend for the "I-d", his data for L 1-2 and L 2-3 show slight, statistically insignificant temporary reversals in this downward trend during childhood. He does not refer to this in the text of his article.

Table 24

Brandner's (1970) data: changes in "I-d"					"I-d" for L 4-5 from present study
Disc	Age Group	No. of Cases	"I-d"	S.D.	
T 11/12	0-1 month	12	0.37	0.060	
	2-18 "	26	0.30	0.065	
	19-36 "	19	0.25	0.089	
	4-14 yrs.	49	0.24	0.053	
	over 12 "	21	0.18	0.042	
L 2/3	0-1 month	9	0.38	0.075	0.54
	2-18 "	18	0.28	0.089	0.40
	19-36 "	15	0.30	0.083	0.40
	4-12 years	32	0.30	0.049	0.48
	over 12 "	22	0.21	0.051	0.42

Hence the trend with age in Brandner's data does not disagree with the trend found in this study as fundamentally as Brandner's textual description might suggest. Such disagreement as does exist may result from different methods of measurement and presentation in the two studies. Thus. Brandner always measured the 'minimum disc space'. In the present study the disc space is measured midway between anterior and posterior disc surfaces. This is greater than the minimum space, particularly after three years when the central part of the disc changes from a biconcave to a biconvex shape (Text-fig. 15). To measure the minimum space Brandner would require to measure the space farther anteriorly in children than in infants. To measure the 'minimum disc space' in a disc shaped as in Text-fig. 88c would give a false impression of disc height and would require it to be measured near its posterior surface. However, the disc height as measured at a point (Table 8 and Text-figs. 14 & 15) may be altered by changes in disc shape as well as changes in disc height.

Finally, Brandner's age groups are considered too wide in their age range to show a reversal of the trend of "I-d" with age at two years. His group 19-36 months includes those which in the present study have the lowest index (19-24 months) with those showing the most rapid upward change in index (36 months).

Examination of the present data for T 8-9 and L 4-5, together with Brandner's data, suggests that there is a gradual change in the pattern of disc growth in the discs from T 8-9 down to L 4-5. A change in the relative growth rate of L 4-5 disc (total disc/ vertebral body index) in the third year of life is less obvious in L 2-3 disc and is almost or entirely absent in T 8-9 disc. This change in the lower lumbar disc growth rate coincides with a gradual change in the shape of the lumbar centra (from convexity towards the disc to concavity towards the disc), a change which is slight or absent in thoracic centra.

(c) Vertical Growth of the 'Disc Proper' and Cartilage Plates. No published work can be found recording vertical measurements of these structures, though Schmorl & Junghanns (1959) and Donisch & Trapp (1971) state that the cartilage plates become thinner with increase in postnatal age.

In the present study, three vertical measurements are made as described (page 50) on each cartilage plate and on the 'disc proper' in median sagittal sections. (i) 'Disc Proper' The mean height of the central third of the 'disc proper' (D.P.) is plotted for each of L 4-5, T 8-9 and C 5-6 (Text-Fig.37). The three growth curves have a similar form up to two years, the rate of vertical growth decreasing with increasing maturity. In the case of L 4-5 there is an apparent slight increase in growth rate beginning at two years which is not seen in the growth curves for T 8-9 or C 5-6. Examination of the tracings of median sagittal sections (Text-fig. 44) shows that the notochordal nucleus pulposus, particularly in lumbar discs, is the structure principally affecting the height of the central part of the 'disc proper'.

(ii) Cartilage Plates: The sum of the mean thicknesses of the central thirds of the cartilage plates and their two component parts ('cartilage layers' and growth plates - see p.49) are plotted for L 4-5, T 8-9 and C 5-6 (Text. figs.33-35). Though there is some reduction in the thickness of the growth plate during the period studied, changes in the cartilage plate thickness are principally due to changes in 'cartilage layer' thickness.

The 'cartilage layers' show increase in thickness prenatally and decrease in thickness postnatally, but in L 4-5, after two years the 'cartilage layers' again increase in thickness. These changes in thickness are statistically significant for L 4-5 and T 8-9, but too few data are available to show statistically significant changes in the cervical 'cartilage layers' (Table 9(d), page120).

(iii) Influence of the Notochordal Nucleus Pulposus on 'Cartilage Layer' Thickness. There is no evidence that the 'cartilage layer' thickness is influenced by bony vertebral growth. Though it could be postulated that horizontal vertebral growth would stretch out a given volume of cartilage, the volume of the cartilage layer is not static. Its horizontal dimensions increase rapidly at all stages observed and its thickness increases at some stages of development as described above. It is readily apparent on observation of midline sagittal sections of discs from foetuses infants and children that the cartilage layer is usually thinnest opposite the maximum 'bulge' of the notochordal nucleus pulposus wherever that bulge may be. Thus it appears that the size and position of the notochordal nucleus pulposus influence the thickness of the cartilage layer as measured in this study.

Influence of the size and position of the lumbar notochordal nucleus pulposus on cartilage layer measurements: Only large notochordal nuclei pulposi come into contact with the 'cartilage layers' as a rule. In foetuses, inner cell zone tissue often intervenes between the notochordal tissue and the cartilage. Three arbitrarily sited measurements are made of each 'cartilage layer'. The localised maximum bulge of the full-term foetal nucleus pulposus often comes into direct contact with both 'cartilage layers' only at the most posterior of the three measurements. At the other two sites of measurement, the 'cartilage layer' is thicker and the tissue adjoining it is the inner cell zone. In infants and children the more centrally situated large diffuse 'bulge' of the lumbar notochordal nucleus pulposus (Text-fig 44) comes into contact with a wider area of the cartilage layer and influences two or even all three of the 'cartilage layer' measurements, until about five years when the horizontal extent of the notochordal nucleus pulposus becomes smaller.

D. HORIZONTAL GROWTH OF THE VERTEBRAL COLUMN

There is relatively little published work on horizontal growth (cf. vertical growth) and such work as there is refers to growth of vertebrae. Knutsson (1961) infers from the position of a Schmorl's node in lateral radiographs of the same individual at different ages that appositional growth takes place at the anterolateral surface of the vertebral body but that there is no posterior growth. Siegling (1941) Larsen & Nordentoft (1962) O'Brien (1969) and Katzman (1969) conclude from the 'bone within a bone' image of growth arrest lines that horizontal vertebral growth takes place principally at the anterior surface. On the other hand, Reichman & Lewin (1972) find evidence of "an intramembranous ossification of moderate cellularity" at the posterior surface of lumbar vertebrae of cases up to 12 years. After 12 years this was not observed. They also describe enchondral horizontal growth in lumbar neurocentral joints in children up to about three years old.

Horizontal Measurements:

Farfan et al (1972) record the coronal diameter/sagittal diameter of 35 adult lower lumbar discs as an index varying from 1.3 to 1.7 with a mean of 1.50. Plaue (1972) and Brandner (1972) record the sagittal diameter of the adult vertebral body as a ratio of its vertical diameter.

Studies in lateral radiographs, comparing the vertical and sagittal diameters of vertebral bodies, are undertaken by Brandner (1970) in normal children, by Robinowitz & Moseley (1964) in children with Down's syndrome and by Houston & Zaleski (1967) in both active and inactive mentally retarded children.

Antero-Posterior and Lateral Diameters

Lippert and Lippert (1960) record the coronal and sagittal diameters of all the 'vertebral bodies' in 80 foetuses and Knutsson graphs coronal and sagittal vertebral body growth (L 1) from measurements on radiographs of 175 normal individuals aged from one to twenty years.

In the present work, coronal and sagittal diameters are recorded for the postmortem discs C5-6, T8-9 and L4-5 (Table 10). Graphs of antero-posterior and lateral growth are shown separately and antero-posterior growth relative to lateral growth is plotted using the index A.P.D/L.D. (Text-figs. 38 & 43).

The growth curves of both antero-posterior and lateral diameters of all these discs appear smooth, except for an increase in the antero-posterior growth rate of L4-5 during the third postnatal year. The A.P.D/L.D. index for all three discs decreases prenatally and increases postnatally. A sharp increase in antero-posterior growth relative to lateral growth is noted for T8-9 in infancy and for L4-5 in the third year of life. Successive increments in the antero-posterior diameter of L4-5 are consistently less than the correspon-ding increments in lateral diameter for all stages up to two years, but after two years the situation is reversed.

The coronal and sagittal diameters of L4-5 are also measured on radiographs, and the changes recorded in the x-ray APD/LD index during infancy and childhood are similar to those demonstrated in the post-mortem material.

Vertebral horizontal growth follows disc horizontal growth fairly closely (although measurements of median sagittal diameters of discs and vertebrae made in midline sections differ slightly due to posterior bulging of the disc and posterior concavity of the vertebral body in the midline). Lippert & Lippert's (1960) data are used to calculate APD/LD in discs for the vertebral body of L4 in foetuses and Knutsson's (1961) data are used to calculate a similar index for L 1 in infants and children.

The trends in their indices are similar to those for the disc L4-5 in the present study (Table 25).

Table 25 /

Table 25

Comparison of present data with data from Lippert (1960) and Knutsson (1961)

Age	Mean Index A.P.D./L.D. from three sources			
	Present Series (L4-5)		Lippert (L4)	Knutsson (L 1)
	Postmortem	X-ray		
4 lunar m.	0.64		0.64	
6 "	-		0.61	
$7\frac{1}{2}$ "	0.59		-	
10 "	0.55		0.53	
1 year	0.59	0.56	-	0.58
2 "	0.59	0.55	-	0.70
3-4 "	0.64	0.64	-	0.69
5-8 "	0.69	0.68	-	0.70
8-10 "	0.74	0.70	-	0.80

(Since L.D. for L 4 $>$ L.D. for L 1 and A.P.D.s are equal, the A.P.D/LD. index for L 4 $<$ A.P.D./L.D. index for L 1).

3. Anterior and Posterior Growth in the Median Sagittal Plane

(a) Persistance of Notochordal Remnants. In this study, 'notochordal remnants' (i) in the cartilage plates (Text-fig. 10) and (ii) in the vertebral bodies (Text-fig.56) are used as 'fixed points' from which anterior and posterior growth is assessed.

(i) The remnants in the cartilage plate are described in detail by Böhmig (1930) though most subsequent descriptions of disc development ignore this aspect of his work. Keyes & Compere (1932) appear to be unaware of it when they assert that Schmorl's view (1959) of a developmental cause for intraspongious prolapse of an intervertebral disc related to a weakness in the cartilage plate at the site of the former notochordal canal, has no demonstrable embryological basis. Funnel-shaped diverticula from the notochordal nucleus pulposus into the cartilage plates (Text-fig. 10) are found in almost all cases in the present series. At these sites the thickness of the cartilage plates is considerably reduced (Text-fig.79). Böhmig (1930) states that these remnants persist until adult life, and that prolapses of disc material through the cartilage plate, frequently observed in adolescents and adults by Schmorl (cited by Böhmig 1930) occurs through the weak point associated with this persistent notochordal remnant.

The vertical alignment in the median plane of 'Schmorl's nodes', found in a number of adult vertebral columns in the present study, supports this suggested aetiology, viz. a fracture through a constantly situated thin part of the cartilage plate at the site of the former notochord.

(ii) Cartilage nodules, 'residue of cartilage in the developing vertebral body centre' are referred to by Schinz et al(1952) as visible at an early stage of ossification.

Cartilage nodules or islands, and fibrocartilaginous cylinders are described persisting in the vertebral centra of 15 foetuses, infants and children in this series (out of 58 cases from 25 weeks to ten years, Table 18, Text-figs. 56-59).It is considered that these cartilage nodules and cartilage cylinders persist along the line of the former notochord. It is suggested that they persist in this situation because in some way the mucoid streak or persistent notochordal tissue inhibits or resists ossification (Taylor, 1972).

(b) Segmental Flexures of the Notochordal Track. The course of the notochord through the vertebral column of 20-30 mm. embryos is straight, but segmental flexures (Text-figs. 5 & 6, and p.26) appear in 50 mm. embryos (Prader 1945).

Schaffer (1910), in order to explain the existence of segmental flexures of the mucoid streak in early foetuses, claims that the mucoid streak is fixed in the bone of the developing centrum but that it moves within the cartilage, in response to changes in position of the nucleus pulposus. This is not supported by observations of the mucoid streak in the present investigation.

Segmental flexures of the mucoid streak are seen from the 13 week (75 mm) stage onwards. As the mucoid streak passes from the centre of the vertebral body towards the cartilage plate it is directed obliquely forwards (A flexure of Type A - Prader (1945) see Test-fig. 6). Such flexures are apparent in the cervical region of the 13 week specimen before there are any signs of ossification (or calcification). During foetal life, as the developing notochordal nuclei pulposi move backwards within thoracic and lumbar discs, the remnants of the mucoid streak in the 'cartilage layers' usually becomes detached from the more posteriorly situated notochordal nuclei pulposi, and the line joining the notochordal remnants in centra and 'cartilage layers' retains the same (Type A) orientation, being directed obliquely forwards from the cartilage nodules in the centra towards the funnel-shaped depressions in the cartilage layers, and away from the notochordal nuclei pulposi.

Thus laying down of bone is not necessary to 'fix' the mucoid streak in the vertebral body, and within the cartilage layer, though a slight backward twist of the end of the mucoid streak nearest the 'disc proper' may be seen, the mucoid streak or its remnant remains 'fixed' in the 'cartilage layer' as the notochordal nucleus pulposus extends posteriorly away from it.

In one case (37 T) the orientation of the 'notochordal cylinders' corresponds to the flexures described as 'Type B' by Prader (1945). No explanation can be offered for the unusual orientation in this case.

If the mucoid streak does not migrate within the vertebral body and cartilage plates (there is no reason to suppose that it does) the change from a straight notochord in nine week (30 mm) embryos, to a segmentally flexed mucoid streak in a 13 week (75 mm) foetus suggests greater growth posterior to the notochord at the level of the cartilage plates than at the level of the centre of the vertebral body.

(c) Comparison of Dimensions Anterior and Posterior to 'the Notochord'. Changes with age in the horizontal dimensions from the notochord and its remnants to the anterior and posterior borders of the vertebrae and intervertebral discs in the median plane (Tables 11 a,b,c), while they show minor individual variations, show in general:

(i) that in embryos posterior growth from the notochord exceeds anterior growth from the notochord in both vertebral bodies and 'total discs'.

(ii) that in children, anterior growth from the notochord exceeds posterior growth from the notochord in both vertebrae and 'total discs'.

(iii) That the gradual transition from (i) to (ii) takes place at an earlier stage in vertebrae (foetal life) than in discs (post-natally) This agrees with the explanation offered for the appearance of 'notochordal flexures' in foetal life. However it also suggests that if two attached structures, which keep substantially the same relative horizontal dimensions have different patterns of growth, ((i) the 'cartilage layers' plus the 'disc proper' and (ii) the centrum) they may require to readapt their relationships where they adjoin one another, e.g. by "slipping", possibly at the growth plate - 'cartilage layer' junction (Solomon (1966) states that in the femur, transverse growth of the epiphyseal (growth) plate is peripheral and appositional as in the diaphysis). In addition, as horizontal vertebral growth is appositional in the foetus and infant, and growth of the disc and 'cartilage plates' is said to be interstitial (Hirsch & Schazowicz, 1953; Donisch & Trapp, 1972), readjustments at their contiguous surfaces would seem to be necessary during growth. In a number of cases (e.g. 24 T, 43 L (Text-figs.80&81) oblique angulation of the growth cartilage columns of the vertebral bodies away from the vertical towards the nearest anterior and posterior disc margin is seen. This may correspond to the angle of entry of Sharpey's fibres but it may also be due to horizontal interstitial growth in the 'cartilage layer' and lack of comparable growth in the neighbouring bone. At the peripheral margins of the growth plate the cartilage columns are bent away from the nearby surface of the vertebral column. This could also be due either to the influence of the direction of Sharpey's fibres, or to the appositional growth of the neighbouring centrum being greater in extent than the interstitial growth in the vertically corresponding part of the 'cartilage layer'.

If it is accepted that midline prolapses of disc proper through cartilage plates take place at weak areas in the cartilage plate corresponding to the site of the former notochord (see page 192) anterior and posterior growth from the notochord between childhood and adult life can be estimated by comparing measurements from notochordal remnants in children with measurements from Schmorl's nodes in adults.

Though the line joining notochordal remnants in the thoracic vertebral column shows segmental angulation at birth it is almost straight in three year and seven year cases. This could be explained on the basis of the considerable vertical growth between birth and three years, without any further differences in horizontal growth from the notochordal. Since the line referred to is almost straight in children, measurements from Schmorl's nodes in adults are compared with measurements in both vertebrae and discs in children. Such comparison (on the basis of the proposed aetiology of Schmorl's nodes) suggests that in the thoracic vertebral column about 10 mm. of growth are added anterior to the line of the notochord between seven years and adult life while only about 1.4 mm. or less are added posterior to the notochord after seven years. Similarly in the lumbar vertebral column anterior growth exceeds posterior growth between childhood and adult life. It would appear that growth has almost ceased at the posterior surface of vertebrae and discs by six years. This gives qualified support to the view of Reichmann & Lewin (1972) who describe histological signs of growth at the posterior surfaces of lumbar vertebrae up to the age of 12 years. The present study does not support the contention of

Knutsson (1961) that no growth takes place at the posterior surface of lumbar vertebral bodies after birth, since the data (Table 11) shows the adult dimension from Schmorl's nodes to the posterier surface of the vertebral column to be on average 14.3 mm. compared with corresponding dimensions of 5.25 mm. at birth and 7.2 mm. at 10 months.

The neurocentral joint is said to close at about 3-6 years and enlargement of the sagittal diameter of the neural canal is almost complete by this time (Knutsson, 1961; Hanson, 1926). Continued growth at the posterior surface of the vertebral bodies after closure of the neurocentral joint could narrow the vertebral canal.

On the basis of experiments in chick embryos, Watterson et al (1954) conclude that girth of the neural tube influences the calibre of the vertebral canal. Donaldson (1903) shows that the transverse sectional area of the human spinal medulla continues to increase during infancy and childhood. It may be that after closure of the neurocentral joints the continued growth of the spinal medulla in some way inhibits further posterior growth of the vertebral bodies. There is some evidence in the present study (Table 11 and Text-figs. 40&50) that this posterior growth slows down at an earlier age in the thoracic region than in the lower lumbar region. This could argue in favour of the size of the spinal medulla and cauda equina influencing the extent of posterior growth of vertebral bodies and discs. However, other factors, e.g. remodelling of bone in the vertebral arch, may influence the size of the vertebral canal and in adults (five dissecting room specimens) the average sagittal diameter of the vertebral canal at T 8 is approximately equal to that at L 4.

(d) <u>Changes in the Position, Shape and Size of the Notochordal Nucleus Pulposus</u>. Text-figs.44-49and Table 10 show changes in the shape, position and size of the notochordal nucleus pulposus.

(i) <u>Position and Shape</u>. Prenatally, the thoracic and lumbar notochordal nuclei pulposi expand principally in a posterior direction but the cervical notochordal segment, which does not expand notably in the early foetus, assumes a typical 'C' shape with its superior and inferior ends projecting posteriorly (Text-figs. 76a&b). In the absence of notable increase in notochordal tissue "inner cell zone" tissue fills the centre of the cervical disc, extending forward into the concavity of the C shaped notochordal segment. The posterior position and 'wedge' shape of newborn thoracic and lumbar nuclei pulposi conform to the existing primary curvature of the corresponding regions of the vertebral column. The thoracic nucleus pulposus retains this shape and position postnatally but between ten months and two years the lumbar notochordal nucleus pulposus moves anteriorly, assuming a wedge shape at two years resembling a mirror image of the wedge shape at ten months (Text-fig. 44 ii).

When the cervical notochordal nucleus pulposus develops by birth it usually forms a regular centrally situated elipse (as seen in median section). In cases nos. 46 (14 months) and 55 (3yrs. 9m.) where large cervical notochordal nuclei pulposi are seen, the main mass of these nuclei is anteriorly situated and their wedge shape conforms to the secondary cervical curvature.

Thus the position and shape of the notochordal nucleus pulposus correlate well with the local vertebral column curvature and a change in curvature is associated with a change in shape and position of the notochordal nucleus pulposus. The notochordal nucleus has a viscous fluid consistency and therefore its shape could be expected to conform to changes in vertebral column curvature.

In newborn lumbar discs the posterior rounded end of the notochordal nucleus pulposus abuts on the lamellar anulus while the tapering anterior end of the nucleus is surrounded by 'inner cell zone' tissue. In the child on the other hand, the anterior rounded end of the lumbar notochordal nucleus pulposus abuts on the lamellar anulus and the narrower posterior end abuts on fibrocartilage which may be derived from the 'inner cell zone'. It would appear that the change in position of the lumbar notochordal nucleus during later infancy and early childhood involves either displacement of the 'inner cell zone' tissue lying anterior to it at birth, or liquefaction of this 'inner cell zone' tissue into the notochordal nucleus pulposus, or both.

(ii) Size. The lumbar notochordal nucleus pulposus attains its maximum size relative to the size of the disc, during infancy, when it occupies three-quarters of the antero posterior extent of the disc in the median plane (Table* 20). Just as vertical expansion of the notochordal nucleus pulposus in infancy is associated with decrease in thickness of the cartilage layers, so horizontal expansion of the notochordal nucleus pulposus is associated with thinning of the 'anulus' (i.e. anatomical anulus plus 'inner cell zone' - Text -fig. 39) during infancy.

Horizontal Growth as measured by Area of Horizontal Outline

The changes with age in the horizontal sectional area of the disc and notochordal nucleus pulposus (as illustrated in Text-figs. 44-49): The growth curves for the discs are quite smooth but those for the

* see p. 159

notochordal nucleus pulposus of L 4-5 show a reduction in its rate of horizontal growth in the second year of life which is both absolute and relative to horizontal growth of the whole disc. A relative reduction in the nuclear growth of T 8-9 is seen in infancy. In the third year, horizontal growth of the nucleus of L 4-5 (Text-fig. 42). resumes the same rapid rate as in the first year of life, but by five years the horizontal areas of the notochordal nuclei pulposi (T & L) decline. This decline in horizontal area takes place earlier than the recorded decline in volume of the lumbar notochordal nucleus pulposus (Table12a and Text-fig. 41), as the average height of the lumbar nucleus continues to increase after its horizontal area has begun to diminish (though volume of the nucleus varies considerably comparing cases 57 and 58 at five years).

E. MECHANISM OF GROWTH IN THE DISC

One may consider separately the growth of the notochordal nucleus pulposus, in terms of increase in notochordal tissue, and growth of the 'envelope' containing it viz. the anulus fibrosus and the 'cartilage layers', but it is not possible, when considering mechanisms of growth, to separate entirely growth of the notochordal nucleus pulposus from expansion of its 'envelope'.

Increase in the volume of the foetal lumbar notochordal nucleus pulposus is principally due to an increase in the number of notochordal cells (a X 30 increase in volume and a X 18 increase in cells from 18 weeks to 40 weeks).

Postnatal increase in the volume of notochordal tissue is almost entirely by the production of clear mucoid matrix (a X 10 increase in volume and a X 2 increase in cells from birth to three years).

This matrix may be derived either from the notochordal cells or from the tissues of the surrounding 'envelope' or from both sources. The absolute volume of the notochordal nucleus pulposus of L 4-5 is maximal from three to five years. Over the period from three to seven years the notochordal cells gradually disappear, the clear mucoid matrix is replaced by randomly oriented collagen bundles and the notochordal nucleus pulposus as defined disappears.

1. <u>Mechanism of Expansion of the Notochordal Nucleus Pulposus</u>

The notochordal nucleus pulposus may expand both prenatally and postnatally by liquefaction of the tissues bounding it (Peacock, 1951). In the present study, necrotic lamellae of the anulus are seen well within the notochordal tissue (Text-figs.73&74) and degenerative changes are seen in tissues bounding the notochordal nucleus pulposus from the 18 week foetus at all stages up to the three to five year children. Mixing of 'inner cell zone' tissue with the peripheral part of the notochordal area, described in embryos by Walmsley (1953) is seen in foetuses and infants in the present series, but since the notochordal matrix remains clear and the scattered cells with small elongated nuclei like fibroblasts remain confined to the periphery of the notochordal area during foetal life and infancy, it seems likely that they are 'liquefied' as the notochordal nucleus pulposus expands.

2. <u>The Role of the Notochordal Cells</u>

(a) <u>The Vesicular Appearance' of Notochordal Tissue</u>. The notochordal cells have a similar appearance at all stages from the 30 mm. embryo to the young child. One of their most characteristic features from the 30 mm. stage onwards is the appearance of intra cellular vacuoles, inter cellular globules and the progressive accumulation of a clear mucoid matrix which splits up the notochordal cell mass into a reticulum. This matrix which has a similar appearance to the intercellular and intracellular material, is only found in the nucleus pulposus so long as notochordal cells are present, and would therefore seem to arise from them.

The vesicular appearance of the cells is referred to by some authors (Link, 1910; Böhmig, 1930; Keyes & Compere, 1932) as mucoid degeneration. However, as it is seen in embronic cells which are continuing to increase in number (as seen in successive stages of nuclei pulposi) and since vesicular appearances, volume of mucoid matrix and the number of notochordal cells all continue to increase concurrently throughout foetal life, it is more likely to be a secretion process.

(b) Interaction of Notochordal Cells with surrounding Tissues. Keyes and Compere (1932), Prader (1945), Peacock (1951), Walmsley (1953) and But (1959) describe 'interaction' between the notochordal cells and cells of the 'inner cell zone'. But (1959) states that the 'soft central mass' of the nucleus pulposus is formed by this 'interaction'. Prader (1947b) states that the 'inner cell zone' contributes to growth of the anulus while Peacock (1951) and But (1959) describe it as contributing to growth of the nucleus pulposus. Peacock (1951) & Walmsley (1953) describe degenerative changes in the 'inner cell zone' associated with expansion of the nucleus pulposus.

The present study finds that in embryos the 'inner cell zone' is highly cellular and occupies most of the centre of the disc. Though it fills the centre of those foetal cervical discs in which the notochordal segment remains rudimentary, and of those few newborn and infant cervical discs from which notochordal tissue has disappeared, a large notochordal nucleus pulposus occupies the centre of a typical foetal or infant lumbar disc. In such a disc the 'inner cell zone' is restricted to a band of variable width around the notochordal nucleus pulposus and it has a transitional appearance (page 157) when traced from notochordal nucleus to lamellar anulus. During foetal and infant life the average volume of this zone increases at about the same rate as the average volume of the notochordal nucleus pulposus.

These facts, together with the observation of degenerative changes in the 'inner cell zone' where it adjoins the notochordal tissue suggest that in most discs (i.e. lumbar discs, thoracic discs and some cervical discs), 'inner cell zone' tissue is being actively produced, only to degenerate at its inner margin and be incorporated into an expanding notochordal area, perhaps under the influence of the notochordal cells.

Fell (1969) observes that in certain conditions cartilage cells or osteocytes in culture become filled with vacuoles as their surrounding matrix disappears. She suggests that the cells 'digest' the matrix (i) by release of enzymes and (ii) by endocytosis of partially digested matrix, union of vacuoles with lysosomes, and discharge of the products. Notochordal cells may act in this way in 'liquefaction' of 'inner cell zone' or inner anulus tissue to produce clear mucoid matrix. It is of interest in this respect that Robin (1868) after conducting in vitro experiments on fresh notochordal cells considered that the accumulation and disappearance of droplets in these cells were reversible processes.

(c) <u>Comparison with Chordoma</u>. Walmsley (1953) compares the action of embryonic notochordal cells to that of chordoma cells, and describes notochordal cells as 'invading' the surrounding 'inner cell zone'. Chordoma cells are known to be of notochordal origin (Friedman et al, 1962), to be locally invasive (Harvey & Dawson, 1941) and to produce necrotic changes in the tissues they infiltrate.

Chordoma cells observed in the present study closely resemble the notochordal cells in developing intervertebral discs. Chordoma cells, whether in muscle, bone or other tissue, are vacuolated, surrounded by a clear mucoid matrix and give rise to necrosis in surrounding tissues. Though some tumour masses are surrounded by a 'false capsule', most chordoma cell masses merge with and infiltrate the surrounding tissues. In this study, such a degree of infiltration of the 'inner cell zone' or inner anulus by notochordal cells cannot be found and the probable mechanism of extension of the notochordal nucleus pulposus is described as necrosis of surrounding tissue, which 'peels off' and disintegrates or liquefies, among the notochordal cell clumps. However, notochordal cell clumps in some foetuses and infants are found on both sides of a lamella of the inner anulus (Text-figs.69&71)suggesting infiltration.

(d) Production of Mucopolysaccharides. The mucoid matrix surrounding notochordal cellsstains with Alcian blue. The notochordal cells do not stain but a ring of stain appears around cells and cell clumps (Text-fig. 86). Amprino (1955) and Souter & Taylor (1970) conclude that the notochordal cells produce mucopolysaccharides from autoradiographic studies which show S_{35} incorporation by notochordal cells in small mammals. Wolfe et al (1965) find that the notochordal cells of infants and young children have the enzymes necessary to produce mucopolysaccharides, and Malinski (1958) produces histochemical evidence that they probably do so.

Estimations of the types of mucopolysaccharide present in the nucleus pulposus and in the anulus fibrosus (Hallen, 1962; Gower & Pedrini, 1969) show that the ratio of keratansulphate to chondroitin sulphate is considerably higher in the anulus than in the nucleus during infancy and early childhood. In this study, staining of sections from a 25 week foetus and a four month infant by 0.1% Alcian blue in 0.4M magnesium chloride and in 0.9M magnesium chloride (Stockwell & Scott, 1965) suggest that chondroitin sulphate is fairly plentiful and of approximately equal concentration in inneranulus and nucleus pulposus, while keratansulphate, present in low concentration throughout the disc, is present in even lower concentration in the nucleus pulposus than in the inner anulus fibrosus.

The data of Hallen (1962) and Gower & Pedrini (1969) indicate that increase in the ratio of keratansulphate to chondroitin sulphate rises more rapidly with age in the nucleus pulposus than in the anulus fibrosus so that the difference in mucopolysaccharide pattern in the two regions diminishes as age increases.

The different mucopolysaccharide patterns, comparing the anulus and nucleus in infancy, are associated with the different cell populations of the anulus and nucleus during that period. This provides additional evidence that the notochordal cells rather than the cells of the 'inner cell zone' or anulus produce the mucopolysaccharides of the nucleus pulposus during infancy.

(e) <u>Persistence of Activity in Postnatal Notochordal Cells</u>. Bradford & Spurling (1945), Prader (1945), Peacock (1951), Walmsley

(1953) and But (1959) regard the multiplication of notochordal cells as confined to the first half of prenatal life, and describe 'degenerative changes' in notochordal cells with reduction in their numbers from early foetal life. Bradford & Spurling (1945) state that in the full term nucleus pulposus they are inconspicuous and Prader (1945) states that all notochordal cells seen in the newborn nucleus pulposus show degenerative changes.

Malinski (1958), on the other hand, describes a widespread chorda reticulum in full term foetuses, and states that they continue their activity (e.g. mucopolysaccharide production) during infancy and early childhood.

Meachim and Cornah (1970) describe the cell population of the neonatal nucleus pulposus as notochordal, and they illustrate the appearances of these cells. They state that the notochordal cells undergo necrosis in early infancy and describe 'non-notochordal' tissue as occupying the outer part of the 'nucleus pulposus' in a one year specimen and as constituting almost the entire 'nucleus' by four years.

The present study finds that the notochordal cells retain essentially the same appearances from embryonic life throughout foetal life, infancy and until early childhood in many cases, i.e. round or oval well defined nuclei of normal appearance, vacuolated eosinophilic cytoplasm, the cells appearing in a reticulum, as clumps or strands and whose variations in form appear to depend on the relative proportion of cells and matrix. Rough estimates of the number of notochordal cells, (Table 13 and Text-fig. 12) show that they continue to increase during infancy. Though degenerative changes in large numbers of cells (i.e. shrinkage of cells, loss of cytoplasmic staining and pyknotic nuclei) may be seen in one ten month infant and some young children, larger numbers of notochordal cells still appear healthy. Thus the average number of notochordal cells is found not to diminish until after 3-5 years.

The two types of cells which appear to be multiplying in or around the central part of the intervertebral disc during foetal life, viz. the notochordal cells and cells of the 'inner cell zone' could be regarded as competing for the central area or 'nucleus' of the disc. The notochordal cells appear to remain dominant in this area during foetal life and infancy in lumbar discs, many thoracic discs and some cervical discs.

Foetal and infant lumbar notochordal nuclei pulposi have usually clear cut regular margins, and apart from localised mixing of notochordal cells and 'cartilage cells' at the periphery of some notochordal nuclei pulposi, the notochordal areas are populated only by notochordal cells in a clear matrix. Notochordal nuclei pulposi of young children on the other hand, may contain many notochordal cell clumps in a matrix no longer clear and homogeneous but containing much visible cell debris, some of it possibly notochordal but most of it probably cartilaginous, and there is more extensive mingling of notochordal and fibrocartilaginous tissues at the periphery of the notochordal area.

Such notochordal cells appear to produce mucopolysaccharides which differ from those produced in the inner anulus, the persistence of a different pattern of mucopolysaccharides in the nucleus pulposus until it contains a different population of cells may indicate some continued activity of notochordal cells during childhood. The lessening of this difference between anulus and nucleus as the notochordal cells disappear may be taken to suggest that the cells populating the nucleus pulposus during childhood and adolescence are similar to the cells of the anulus fibrosus.

3. The Decreasing Vascularity of the 'Total Disc' and its Role in Changes in the Character of the Nucleus Pulposus.

Brodin's (1955) fluorochrome diffusion experiments in immature rabbits show the probable role of vessels of the cartilage plate in nutrition of the intervertebral disc. Uebermuth (1929) and Böhmig (1930) describe the decrease in vascularity of the human 'total disc' with increase in maturity. In the present study, as the volume of the disc proper increases, the vascularity of the cartilage layers bounding it decreases (Text-fig. 41).

The nucleus pulposus itself is avascular, but during foetal life and infancy the anulus and 'cartilage layers' have a good blood supply (Text-figs. 93-100). The blood supply in the anulus is less rich in children, and blood vessel counts in the cartilage layers show a sudden drop after infancy (Table 23). The volume of the notochordal nucleus pulposus is increasing while these vascular changes are taking place. Thus its surface area is relatively decreased and its nutritional position appears to be less favourable in childhood than in infancy, and may become inadequate to maintain its large cell population (Text-fig. 41).

It seems most unlikely that inadequate nutrition is responsible for the tissue necrosis observed at the boundaries of the notochordal nucleus pulposus in foetuses and infants, since notochordal cells survive and even multiply, even though they are further from the blood vessels in the anulus and cartilage layers.

After infancy necrosis is seen in an increasing proportion of notochordal cells. The higher collagen bundle content of the notochordal nucleus pulposus and the less regular outline of its boundary in childhood compared to infancy may represent a slower rate of 'liquefaction' by aging notochordal cells. In a four year nine month lumbar disc from the present series relatively few notochordal cells remain and most of these appear necrotic while in the seven and a half and ten year discs no clearly identifiable notochordal cells are seen and the population of 'cartilage' cells in the nucleus pulposus is sparse. The viable cells of the juvenile nucleus pulposus described by Meachim & Cornah (1970) are not notochordal and these authors find a high proportion of necrotic cells in the juvenile nucleus. Maroudas, Nachemson & Stockwell (1973) suggest that in the adult, nutrition is theoretically inadequate to maintain the life of cells at the centre of lumbar intervertebral discs.

Normal notochordal cells may have a 'built in' life expectancy of only five years or less. However, they have been shown to survive into adult life in some sites (Schwabe 1933, Harvey & Dawson 1941), and thus their death and disappearance from the nucleus pulposus, coinciding as it does with the marked reduction in the blood supply of the disc, makes it possible that this reduction in blood supply is an important factor in their death. The fact that the notochordal cells are replaced by 'cartilage cells' (Meachim & Cornah, 1970) which are known to have a low metabolism and to survive relatively well in avascular situations (Bywaters, 1937) gives additional support to this view.

4. Growth of the Anulus Fibrosus and 'Cartilage Layers'

The external dimensions of the envelope bounding the notochordal nucleus pulposus (APD & LD of disc and 'total disc' height) all increase continuously throughout the period studied, but horizontal growth (of APD & LD) considerably exceeds vertical growth (of 'total disc'). Growth in the thickness of this envelope formed by 'cartilage layers' and 'anulus' (AAF & PAF, Text-fig. 9b) is not continuous throughout the period studied, and for the disc L 4-5 three phases can be described (Text-figs. 33 & 39).

(i) in foetal life the 'anulus' and 'cartilage layers' grow in thickness,

(ii) in infancy both are reduced in thickness, and

(iii) in early childhood both increase in thickness once again.

The decrease in thickness of the 'envelope' of the notochordal nucleus pulposus in infancy, associated with the histological changes observed at its inner margin, seems to give added evidence for its liquefaction internally since it is increasing in external diameter. This pattern of growth (illustrated in Text-fig. 44) suggests an analogy with growth in girth of a long bone diaphysis, viz. external apposition (as in the adjacent vertebral body) and internal liquefaction.

(a) Horizontal Growth. Considering horizontal growth of the disc, though the histological evidence, and the changes in disc dimensions cited support the concept of inner 'liquefaction' of the 'anulus', the relatively small number of cells and the coarse nature of the collagen bundles in the outer layers of the anatomical anulus do not support the view of a significant outer appositional growth. The lamellae of the inner half of the anulus fibrosus are more cellular and their finer collagen bundles are embedded in a more plentiful matrix. Hansen & Ullberg (1960) and Souter & Taylor (1970) show in suckling pigs and immature rabbits respectively that there is active S35 uptake in the inner two-thirds of the anulus and virtually none in the outer third. The S35 appears initially in the cells and subsequently in the pericellular matrix. These observations support the view of Donisch & Trapp (1972) that the anulus fibrosus grows interstitially, but suggest that this growth is most active in the inner half of the anulus. It would appear that new collagen bundles may be formed in the inner half rather than in the outer half of the anulus and that the cells of the inner two-thirds of the anulus are active in the uptake of S35 and probably in the production of a mucopolysaccharide rich matrix, but that in the first two postnatal years, despite this production of fibres and matrix, there is no increase in the thickness of the 'anulus' (Text-fig. 39).

Production of new tissue in the inner half of the anulus, approximately keeping pace with liquefaction of its inner margin is somewhat analogous to enchondral ossification.

(b) Inequality of horizontal and vertical growth. From birth to three and a half years horizontal extension of the notochordal nucleus pulposus (14mm.) considerably exceeds its vertical extension

(3mm.). This agrees with the findings of Peacock (1951) and the present study that changes at the 'cartilage layer' notochordal nucleus pulposus boundery are less obvious than changes at the inner margin of the anulus. The lamellae of the inner two-thirds of the anatomical anulus appear to be continuous with lamellae in the 'cartilage layers' (Text-fig. 83). Lamellae are closely packed and it is not possible to count them accurately or to trace them very far around the nucleus. Schmorl & Junghanns (1959) state that lamellae only partly encircle the nucleus pulposus and may branch and interlock with one another. However, if the notochordal area extended only by liquefaction of its bounding 'envelope' one would expect more anular lamellae than 'cartilage layer' lamellae to be liquefied and consequently to see 'ragged ends' of lamellae at the junction of the anatomical anulus and 'cartilage layer'. These are not a prominent feature an though they are seen occasionally in infants (e.g. case 41) and some cases in early childhood (e.g. case 50, Text-fig. 84) in foetuses and most infants the boundary of the notochordal nucleus pulposus is smooth.

If growth of the anatomical anulus does take place principally in its (lamellae) inner half, the central parts of the 'cartilage layers' containing the (corresponding) horizontal lamellae, must grow in length in order to allow for the observed horizontal extension of the notochordal nucleus pulposus. Moreover, elongation of the outer lamellae must exceed elongation of the inner lamelae in growth of this concentric lamellar structure, despite the relatively less cellular appearance of the outer anatomical anulus. Souter & Taylor (1970) observed intense S35 labelling of the cells in the peripheral parts of the rabbit cartilage plate (the central part of the plate is occupied by the bony epiphysis). Since the outer lamellae of the anatomical anulus pass through this region, if the sulphate uptake activity of the chondrocytes can be taken as indicative of their general level of activity, one may expect a considerable part of the lengthening of these outer lamellae to take place within the cartilage. Amprino & Bairati (1934) and Peacock (1951) describe the "transitional zone" ((b), Text-fig. 1) where the anulus joins the cartilage plate as a prominent structural feature in the growing disc. Uebermuth (1929) and Donisch & Trapp (1971) state that the blood vessels of this zone play a part in the growth of the anulus.

The concept of interstitial horizontal growth in the 'central' part of the 'cartilage layer' is supported by the observation (see p. 163 and Text-figs 80&81) of 'outward' deviation of the adjacent cartilage columns towards the nearer anterior or posterior surface of the 'disc proper'.

F. MECHANICAL INFLUENCES ON GROWTH

(1) Growth of Bone

(a) Effects of Pressure and Weightbearing. Sissons (1971) states that intrinsic factors are more important than mechanical influences in determining the form of bones. Gelbke (1951) reviewing the literature on bone growth, attributes to Hueter (1862), and Volkman (1862) the 'classical' view that pressure inhibits bone growth and tension increases it. He attributes to Wolff (1892) the view that both pressure and tension increase bone growth. McMaster & Weinert (1970) state that minute compressive or distractive forces increase growth in cartilage but that large forces decrease growth.

Volkman (1882) is the first to apply this view of inhibition of bone growth by pressure to a hypothesis on the aetiology of scoliosis. Bick (1958) suggests that a fixed eccentric nucleus pulposus, by unequal distribution of vertical pressures leading to unequal bone growth, may produce the bony deformities of scoliosis. Maas (cited by Gelbke, 1951) claims that decrease in longitudinal bone growth due to pressure in the long axis of the bone is compensated for by increased growth in girth. Gelbke (1951) demonstrates that in canine femora pressure perpendicular to the growth plate narrows the plate and eventually inhibits growth, but states that very large forces are required. He concludes that tension may also inhibit growth or lead to premature closure of the epiphyses. Arkin (1949 and 1956)believes that pressure can inhibit bone growth, and states that though large pressures are necessary to arrest growth, gravitational pressures may slow growth in weight-bearing bones. These conclusions result from experiments in rabbits prevented from weight-bearing with one limb, with resulting overgrowth in the non-weight-bearing limb. Arkin (1956) supports the view of Maas (cited by Gelbke, 1951) that decrease in longitudinal growth is compensated by increased growth in girth. Gelbke (1951) on the other hand shows that in femora whose longitudinal growth is reduced by pressure, there is no increased growth in girth.

Changes in the Ratio of Vertebral Height to Antero-posterior Diameter.

Gooding & Neuhauser (1965) claim that human vertical vertebral growth is increased in the absence of the normal stresses of weight-bearing. They support this view by publishing lateral radiographs of lumbar vertebral bodies in which the vertical diameter exceeds the sagittal diameter. One is a case of motor neurone disease, another a case of trisomy 18, and the third a case of cerebral palsy in three children who have never walked. They do not record the dimensions of the vertebrae or give the dimensions of normal vertebrae of comparable age nor do they record the height of the children. It is possible that the vertebrae in these cases may have an increased height, but this is not demonstrated; alternatively, a decreased antero-posterior diameter could explain their unusual shape. Rabinowitz & Moseley (1964) describe abnormally shaped lumbar and thoracic vertebrae in infants with Down's syndrome. These vertebrae are relatively small in sagittal diameter, relatively great in height and the index sagittal diameter/vertical diameter is given as an average of 0.93 for 24 mongoloid children contrasting with an average of 1.28 for 36 non-mongoloid children of comparable ages. The data given show an increase in this index with age in both groups, i.e. there is relatively greater antero-posterior than vertical growth and though the two groups are genetically different, increase in age (and possibly activity) is accompanied by similar changes in the index.

Houston & Zaleski (1967) compare the 'height index' (height/APD) (similar to the "I-vb" of Brandner, the inverse of the index of Rabinowitz & Moseley) in lumbar vertebral bodies of active and inactive mentally retarded children of similar age. The mean index for fully active children at 0.73 contrasts with that for inactive recumbent children at 0.99 (i.e. activity correlates with relatively greater antero posterior growth, inactivity with relatively greater growth in height). At any given age, the index (i.e. height/APD) shows a progressive increase with decrease in grades of physical activity. Those active children who did not walk until after five years have a higher index than those who learned to walk earlier. Houston & Zaleski's work demonstrates a relationship between activity, e.g. walking, and the shape of the lumbar vertebral bodies as seen in lateral X-rays. Since only the indices are given, this result could represent an increase in antero-posterior growth associated with weight-bearing and walking, a decrease in vertical growth associated with these activities, or both. However, Houston and Zaleski conclude that change in shape in the absence of weight-bearing is at least partly due to increase in vertical growth of the vertebral body, associated with a persisting convexity of its upper and lower surfaces. On the other hand, Keegan (cited by Pritchard, 1961) finds that transplanted rat tail vertebrae grow normally in length but not in girth. Pritchard (1961) cites Keegan's work as evidence for the dependence of growth in girth of bones on normal activity.

Although the different authors draw varying conclusions, a similar pattern is seen in the work of Gooding & Neuhauser (1965), Rabinowitz & Moseley (1964) and Houston & Zaleski (1967). In each case antero-posterior and vertical dimensions are compared. Antero-posterior growth relative to vertical growth is seen to increase (i) with age and (ii) with activity. This gives some support to the views of Maas (cited by Gelbke (1951) and Arkin (1956) that vertical pressure decreases vertical growth and increases (horizontal) growth in girth.

In the present investigation, antero-posterior growth, lateral growth and the index A.P.D./L.D. are studied for the intervertebral disc (Text-figs.38&43). An increase in the rate of antero-posterior growth, both absolute, and relative to lateral growth is found in the lumbar region during the years immediately following the assumption of the erect posture (the average child first walks unaided by fifteen months, (Nelson et al, 1969), while the secondary lumbar curvature is being established. It may be noted that in one retarded child (non-ambulant) of eighteen months the A.P.D./L.D. index is markedly reduced. (0.49 compared to 0.59 ± 0.02 for seven cases from six months to two years three months - see Table 10a, page 124). Though Knutsson (1961) and Lippert et al (1960) did not study antero-posterior growth relative to lateral growth their data support the present findings (Table 25, page 191). The vertical growth rate of lumbar or thoracic vertebrae shows a progressive diminution with increasing maturity, but this is a pattern of growth common to most tissues, and it would not be permissible to attribute the gradual reduction in vertical growth rate solely to the effects of weight bearing.

As discussed earlier, available evidence on the effects of weight-bearing and activity on the growth of vertebrae (Gooding & Neuhauser, 1965; Houston & Zaleski, 1967) does not indicate whether the primary effect of weight-bearing is on vertical or horizontal growth. The evidence from measurement in the present study suggests that following weight-bearing, there is -

(i) an increase in the rate of antero-posterior growth in the disc in the third year

(ii) no evidence of a corresponding change in the general trend of lateral growth of the disc or of vertical growth in the vertebral body

(iii) an increase in the rate of vertical growth of the L 4–5 'total disc' relative to that of L 4 vertebral body (Text-figs.31&32) in the third year of life, and ,

(iv) a gradual change in the shape of the cranial and caudal surfaces of the lumbar vertebral bodies (bony) after two years from convex to concave (Text-fig. 88). Thus though measurements suggest that changes in the A.P.D./height index of a vertebra with age are due to changes in its rate of anteroposterior growth rather than in its rate of vertical growth, observation of changes in vertebral body shape suggest that following weight-bearing, vertical growth at the central parts of the cephalic and caudal surfaces of lumbar vertebral bodies is less than vertical growth at the periphery of these surfaces. Taking all measurements and observations into account one may reasonably conclude that both changes take place, viz. an increase in the antero-posterior growth rate of the vertebral column and a decrease in the vertical growth of the central part (relative to the peripheral part) of the lumbar vertebral body end surfaces.

(b) <u>The Effects of Posture on Vertebral Body Growth</u>: <u>A possible Relation to Scoliosis</u>.

(i) <u>Abnormal Posture and Vertebral Growth</u>: Browne (1956) asserts that abnormal intrauterine posture is responsible for congenital scoliosis (with shortening of muscles on the concave side). Bick (1958) asserts that the first changes in congenital scoliosis are in the discs, asymmetrical discs leading to abnormal posture and eventually to asymmetrical vertebral body growth. He describes eccentric nuclei pulposi and assymetrical anuli with no evidence of abnormal vertebral growth, as seen in coronal sections from a stillborn foetus and a four-month infant.

Hipps (1961) measures the vertical extent of lumbar vertebral bodies at their anterior and posterior surfaces in lateral radiographs of 30 normal children and eight children of comparable age 'long recumbent' because of poliomyelitis. He describes more rectangular vertebral bodies in the non-ambulant than in the ambulant children, with a relative increase of their posterior heights to equal their anterior heights.

Hipps data for L 4 and L 5	P/A times 100 (normal)		P/A times 100 (long recumbent)
	L 4	91.8	99.7
	L 5	85.9	100.5

(P = posterior vertebral height: A = anterior vertebral height)

In 28 children with an exaggerated lumbar lordosis in association with paralysis of abdominal muscles, Hipps finds a relative decrease in the posterior vertical extent of the vertebral body, i.e. a more wedge shaped L 5 than normal. Hipps also describes 'lateral wedging' of vertebrae in scoliosis associated with muscle paralyses.

Hipps concedes that his measurements may not be "dead accurate". The age range of his cases is from two to 35 years. From observation of radiographs of the vertebral columns of young children one might conclude that it is impossible to measure accurately an anterior or posterior height when the junctions of the vertical outlines with the horizontal outlines are curved , but in older children reasonable accuracy should be possible. (Hipps does not give individual ages but one would deduce from his figures that the average age of his children is over 10 years).

(ii) Normal Posture and Vertebral Growth: In the present study, though the distinctive 'wedge' shape of L 5 is not apparent at birth it develops quite early in post-natal life (e.g. case 40 at $3\frac{1}{2}$ months, case 41 at 4 months and case 44 at 6 months) and may occasionally be foreshadowed by the 'wedge' shape of the 'cartilage outline' of L 5 in a newborn infant (case 21). There is therefore some evidence to suggest that the characteristic shape of the bodyof L 5 is at least partly formed before the secondary lumbar curvature is established. Possibly its shape is influenced by the 'genetically determined' posture of the lumbo-sacral angle, which is evident before birth (Shultz, 1960). Though the 'wedge' shape of L 5 becomes more marked in children than in infants (cf. Text-figs.87&88), if one compares this 'wedge' with a rectangle, the deficiency is at the posterior part of the inferior surface of the normal L 5 vertebral body. Thus the lumbo-sacral angle appears to have a greater influence than the secondary lumbar curvature or the shape of L 5 (the human lumbo-sacral angle is on average 20° at birth increasing to 64° in the adult (Schultz, 1960).

(iii) The Nucleus Pulposus and Posture: Bick (1958) describes the ' fixed eccentric' position of nuclei pulposi in his two cases of congenital scoliosis as the 'primary disorder' which may lead to vertebral deformities by producing abnormal posture.

In the same sense, the L4-5 nucleus pulposus in sagittal sections from normal foetuses and infants is 'fixed' and eccentric with corresponding asymmetry in the anulus, but in normal material the position of the nucleus correlates with the curvature of the vertebral column (see page 198). Indeed the position of the lower lumbar notochordal nucleus pulposus changes in the second year of life to a 'fixed' central or anterior situation. It would be absurd to suggest that the change in the position of the notochordal nucleus causes the child to assume the erect posture.

It is not possible in the present investigation to show which comes first, the new posture, or the change in position of the notochordal nucleus pulposus. However, though one may postulate e.g. genetic factors governing changes in the disc to coincide with assumption of the erect posture, given the fluid nature of the notochordal nucleus pulposus, the mechanical changes associated with assumption of the erect posture and establishment of a secondary curvature would lead to a change in shape of the notochordal nucleus, and could be responsible for anterior movement of the nucleus, by displacement or liquefaction of the tissues (inner cell zone) anterior to it.

If this is so, then postural change leading to change in shape and position of the notochordal nucleus, may thereby influence vertebral shape (and therefore growth in a local sense) since from two to three years onwards the end surface of the vertebra changes from a convex to a flat and eventually to a concave shape. However, (see p. 216) these changes appear to take place only when there is normal weight-bearing (Houston & Zaleski, 1967).

Mechanical Influences on Growth

2. The Intervertebral Disc (Total Disc) The correlation of posture with notochordal nucleus pulposus position has been described.

(Mechanical Influences on 'Total Disc' Growth - continued)

(a) Before two years: Graphs of lumbar 'total disc'/vertebral body index (Text-figs. 23 & 31) show relative deceleration of vertical disc growth postnatally, the index reaching its nadir late in the second year of life. Graphs of lumbar disc growth seem to indicate an absolute reduction in disc growth rate in the second year (a reduction in 'total disc' height in the case of post-mortem material).

(b) After two years: The lumbar index increases in the third and fourth years, and particularly with the post-mortem data, an absolute increase in the rate of vertical disc growth is seen (Table 8a, page 88 and page 93).

The gradual reduction in growth rate after birth, (a), is a general trend. It coincides with the beginning of weightbearing and initial assumption of the erect posture. It is possible that these factorsinfluence vertical disc growth. The increased vertical growth, (b), begins about a year after the establishment of the secondary lumbar curvature, follows change in the notochordal nuclear position, and coincides with the beginning of the change in shape of the bony vertebral end surfaces.

The reduction in L 4-5/L 4 index in the first two years is certainly quite considerable, but its subsequent reversal is even more remarkable, particularly as it contrasts with the behaviour of the T 8-9/T 8 and C 5-6/C 5 indices (see page 184 and Text-fig. 32). Houston and Zaleski (1967) correlate vertebral body growth with activity. They comment also that vertebral bodies are biconvex with thin intervertebral discs in inactive children, while the vertebral bodies become slightly biconcave with thicker discs in active children.

Houston and Zaleski do not emphasise disc differences in inactive and active children. It is suggested here that disc changes in ambulant children may precede and be responsible for the changes in their vertebral bodies.

In the present study, changes in the shape of the lumbar vertebral body end surfaces from the third year of life appear to follow and conform to changes in the position and shape of the notochordal nucleus pulposus. According to Houston and Zaleski (1967) these changes in vertebral body shape only take place in active walking children.

Forward movement of the notochordal nucleus pulposus of L 4-5 to an approximately central position, progressive vertical enlargement of this nucleus and increase in its volume are accompanied by thinning of the cartilage layer and possibly of the growth plate centrally. These changes, with the elevated vertical pressure of weight-bearing, are accompanied by a relative reduction in the growth rate at the central part of the vertebral end surface, leading to the observed change in shape of the vertebral body.

Changes in the vertical growth rates at the central part of the lumbar 'total disc'((a) and (b) above) are the result of successive decrease then increase in cartilage plate thickness, and lesser changes in the vertical growth rate of the 'disc proper' (Text-fig. 37 and page 187).

(a) <u>Reduction in vertical growth in the first two postnatal years</u>. This is seen at both L 4-5 and T 8-9, and in discs at both levels there is a reduction in absolute cartilage plate thickness in this period. Only in L 4-5 is a slight reduction in growth rate of the disc proper demonstrated.

Notochordal Nucleus Pulposus Influence on the Cartilage Layer:

Polarised light study shows some convergence of the lamellar structure of the cartilage layer towards its thinnest part opposite the maximum bulge of a large notochordal nucleus pulposus (Text-fig. 83). This appearance suggests compression of the cartilage layer by the notochordal nucleus pulposus. In addition, some localised necrosis of lamellae, observed at the notochordal tissue/cartilage boundary (Text-figs. 70,77) may be the result of notochordal cell activity (see pages 163 and 202).

Growth Plate: There is a tendency in some infants and children for the growth plate to be thicker peripherally than at its centre and occasionally (e.g. case 55, L, 3years 9 months) cartilage column height is less opposite the maximum 'bulge' of the notochordal nucleus than elsewhere, but these variations are less regular and less marked than those changes described in the 'cartilage layer'. Considering L 4-5 alone, increased activity and weight-bearing may cause some reduction in disc height by other mechanisms -

(i) vertical compression leading to horizontal bulging of the anulus

(ii) loss of water from the nucleus due to increased compression

(iii) possible reduction in growth of the disc tissues (cellular multiplication and production of matrix),

(iv) possible mechanical influences on necrosis and liquefaction of the 'envelope' of the notochordal nucleus pulposus.

(i) Horizontal bulging compensating vertical compression: Virgin (1951) finds that vertical compression of a single adult disc produces only 2/100ths of an inch vertical decrease on continuous application of 'physiological forces' but states that young discs show a large hysteresis (delayed recovery of shape following deformation) and young discs are known to be more readily deformable than older ones (Ballantyne, 1892). On examination of mid-sagittal outlines, there is a subjective impression of more pronounced posterior bulging of the anulus at two years as compared with newborn infants, but measurements provide no evidence of relative increase in horizontal growth in the second year of life to account for any decrease in vertical growth.

(ii) Expression of water: Height decreases following prolonged standing in adults (Cunningham, 1972). This is attributed to loss of water since compression of discs is accompanied by expression of water, and recovery by imbibition of water (Virgin, 1951). The infant nucleus has a higher water content than the adult one and may be more subject to loss in this way.

(iii) Reduction in Growth of the Disc Tissues. Cartilage Layers:

The appearance of 'compression' associated with thinning of the cartilage layer opposite the maximum bulge of the notochordal nucleus pulposus (Text-fig. 83) could be due to localised failure of growth in the cartilage preceding a relative reduction in growth rate in the adjacent central part of the growth cartilage. Though there is evidence for reduced bone growth, in the appearance during childhood of a concavity in the end surface of lumbar vertebral bodies, there is no evidence in this study that the appearance of 'compression' of the cartilage layer is due to failure of its growth (as opposed to liquefaction at its margin).

Notochordal Cells: Schwabe (1933) attributes the longer survival of notochordal cells in sacral disc remnants to the absence of 'mechanical attrition' in that situation. However there is no evidence that mechanical attrition is responsible for the cessation of multiplication of notochordal cells in lumbar discs during infancy and early childhood. The view is advanced (page 209) that reduction of the disc's blood supply is probably responsible for cessation of notochordal cell activity, and for their eventual death.

(iv) Possible Mechanical Influence on 'liquefaction' of notochordal nucleus pulposus 'envelope'. The notochordal cell clumps appear to be more evenly mixed through the notochordal area in L 4-5 than they are in T 8-9. This may be a result of the greater movement in lumbar discs.

The intermediate cell zone tissue lying anterior to the notochordal area in lumbar discs at birth and in early infancy has virtually disappeared by two years.

Maroudas et al (1967), observing the effect of stirring on penetration of a dye solution into cartilage in vitro, suggest that in life, joint movement improves fluid exchange between cartilage and synovial fluid.

Assuming the postulated activities of notochordal cells, by bringing notochordal cells into more intimate contact with previously unaffected tissue, by improving diffusion of fluid (which may contain lytic enzymes) into these tissues, and by increased mechanical attrition of necrotic tissue, movement, assumption of the erect posture, weight-bearing or all three factors may favour increased liquefaction of the 'envelope' surrounding the lumbar notochordal nucleus pulposus. It is possible that the disappearance of inner cell zone tissue from the region anterior to the nucleus pulposus during the second year of life may be due to a mechanical influence on the direction of liquefactive changes.

Despite the possible effects of weight-bearing and movement in reducing vertical growth of L 4/5 in the second year, the continued operation of these factors does not appear to inhibit vertical growth after two years.

(b) Increase in L 4-5 growth rate from two to seven years. This is a more remarkable observation since it is peculiar to the lumbar disc (though there are minor doubtful fluctuations in T 8-9 in females). In the postmortem material this increase is due

(i) to an increase in thickness of the cartilage plates and

(ii) to an increased vertical growth in the disc proper. It is suggested (fig 33) that increased thickness of the cartilage plates after two years might be due to the coincidental cessation of multiplication and activity of notochordal cells and (p.209) a reduced capacity for 'liquefaction' on the part of notochordal cells.

During the whole period (two to seven years) of increased vertical growth at the central part of L 4-5 there is a profound change in the character of the nucleus pulposus from notochordal tissue to soft fibrocartilage, associated with decrease in the blood supply of the total disc. In addition changes in shape of the disc and the adjacent vertebral body centra are observed. However, initially (in the third year) the increase in cartilage plate thickness coincides with an increased growth rate (in volume) of the notochordal nucleus pulposus. This increase is in part due to an increase of fibrocartilaginous elements in the still predominantly notochordal nucleus, but in part is due to continued increase in mucoid matrix. There is evidence of continued liquefaction at the nucleus/anulus boundary and the appearance of 'villous projections', of fibrocartilage necrotic at their edges, at the posterior boundary of the nucleus.

It is suggested (p.207) that the cells of inner anulus and inner cell zone may be regarded as competing for the centre of the disc and that reduction in blood supply to the growing intervertebral disc during childhood (p.208) may be a decisive factor 'tipping the scales' in favour of fibrocartilage, and bringing to an end the life cycle of the notochordal tissue.

Antero-posterior growth of the vertebral column is seen to be in some measure dependant on assumption of the erect posture and bipedal locomotion (Houston and Zaleski, 1967 and the present work). Houston and Zaleski (1967) also observe that there is a lack of vertical growth of the intervertebral discs, particularly of their central parts, in the absence of standing and walking. The present study supports the view that the erect posture and bipedal locomotion lead to an increase in vertical growth of the central part of L 4-5. This is in part due to changes in shape of the disc and the vertebral bodies as seen (and measured) in midline sagittal section and lateral X-rays, but probably not entirely so. The changes in shape of the disc and vertebral bodies are probably due to changes in size and position of the notochordal nucleus of L 4-5. The rapid increase in volume of disc tissue (from two to seven years) is due principally to rapid increase in fibrocartilage probably produced from the inner cell zone or inner anulus. Initially this appears to be liquefied and possibly forms part of the clear mucoid matrix of the notochordal nucleus pulposus, but the increase in fibrocartilage becomes apparent following the decline in notochordal activity and death of notochordal cells which accompany the reduction in blood supply to the disc.

ACKNOWLEDGMENTS

I am indebted to Dr. A.D. Bain for access to the postmortem material used in this study, to Professor J.I.P. James and Dr. W. McLeod for access to radiographic material, to Dr. J.B. King for help and advice in radiographic techniques and to Dr A.F.J. Maloney for access to sections of chordomata.

I wish to thank Professor G.J. Romanes and Dr. R.A. Stockwell, my supervisors, for their patient and invaluable advice, guidance and correction in the preparation and writing of this thesis, Mr T. Paterson for preparation of the photographic prints, and Mrs E. Liddle and Miss S. MacDonald for typing the script.

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