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STUDIES ON STRUCTURAL CHANGES IN THE LUMBAR ANNULUS FIBROSUS

By

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INTRODUCTION

By "low back pain" we mean pains limited to the lower part of the lumbar spine. We know with certainty that such pathological states may arise through many different causes. Kidney diseases, affections of the stomach and intestines, inflammation in or close to the spinal column may sometimes in various ways cause the patient backache as the only symptom. It is quite a striking fact, however, that the great majority of those seeking treatment for pains in the back prove to be otherwise healthy individuals in whom, in spite of the most careful clinical examination, no pathological changes can be found in the above-mentioned organic systems. Accordingly, the medical profession has for a long time shown considerable interest in local changes in the lower part of the back, special importance having formerly been attached to anatomical variations, such as e.g. the number and form of the vertebrae, sacralization, lumbalization, spina bifida, spondylolisthesis, assymetry, scoliosis, etc. When Schmorl et coll. published their studies on the morphology of the intervertebral discs they initiated a new approach to the investigation of spinal lesions. The merit of these scientists is that they have been able to indicate a great many changes within the structure of the intervertebral discs at different ages–changes that might conceivably be connected with and possibly lead to low back pain.

The connection between changes in the disc and lumbar pains was, however, never proved. The structural changes might of course reflect a physiological ageing of the intervertebral disc, such as was perhaps evidenced by the regularity with which it occurred. Many research scientists, moreover, sought to find an explanation of low back pain in functional disturbances in other parts of the back, e.g. in the intervertebral joints and in the ligament apparatus. When Mixter and Barr, Love, Friberg, Lindblom and others were able to show that sciatica was often due to a herniation from a disc, the intervertebral disc came into the forefront of the discussion on lumbago. Since sciatica is generally preceded by attacks of pain limited to the lumbar spine, pain that is exactly described as low back pain, there was a sound clinical reason for assuming that the intervertebral disc was actually responsible for these pains. Ruptures in the annulus fibrosus, which are a prerequisite of disc prolapse, are very common. Pathologically, a disc prolapse is a partial manifestation of degeneration of the disc (Friberg-Hirsch).

If, then, we assume on strong clinical and pathological grounds that low back pain is due to ruptures in the annulus fibrosus, the question naturally arises how such ruptures can produce pain. The problem is, of course, a very simple one in the case of disc prolapse. Here, we can point to a direct pressure on one or possibly several nerve roots in consequence of the local deformation which the intervertebral disc undergoes in a prolapse. But why should an annulus rupture give pain if it does not irritate the nerve roots?

Lindblom and Hirsch have shown that low back pain can be induced from a lumbar intervertebral disc, in which the annulus fibrosus has been ruptured, by an increase of the pressure inside this disc. Such a rise in pressure may be caused by a transdural puncture in the disc and then by an injection of normal saline or a contrast substance (perabrodil). According to Chanley, an injection of this kind may give rise to a swelling of the nucleus pulposus. He believes that vibrations in the water content of the nucleus can give pain. To this it may be objected that an injection of normal saline without pressure does not give pain, and, further, that no evidence has been produced that variations in the water content arise in one and the same disc within a limited period of time. The water content shows in the course of years a continuous decline (Hirsch, Sylvén, Snellman, Paulsson). The experiments carried out by Hirsch offer evidence that the mechanical irritation exerted by the posterior protrusion of the intervertebral disc owing to a rise in pressure produces lumbago of the very same type as the patient had felt before in his attacks of lumbago. In those cases in which pain could be induced from a specific disc, nucleography (Lindblom) has shown the existence of ruptures in the annulus.

In operations for sciatica Wiberg and Hirsch have been able to demonstrate that certain intervertebral discs are extremely sensitive to blunt pressure. Operations have been performed on patients to whom local anaesthetic has been administered in the lumbar musculature down to the lig. flavum. The purpose of this has been to supplement the anaesthesia after the lig. flavum and parts of the arches have been removed. In such cases, before the supplementary anaesthetic has been administered the intervertebral disc has been palpated with a metal probe. In a number of cases, even when only moderate pressure has been exerted against the posterior protrusion of the disc, these patients have declared that they felt intense lumbar pains. Many patients suffering from degeneration of a lumbar disc feel extreme tenderness and a marked sensitiveness to mechanical irritation within the posterior protrusion of an intervertebral disc and here confined to a small area.

The observations described above indicate that lumbago may arise in consequence of mechanical pressure on an intervertebral disc in cases where the annulus has been ruptured posteriorly.

Güntz and Böhmig have observed in autopsy material an abnormal degree of mobility between lumbar vertebrae in cases where the intervertebral disc lying between them has shown serious structural changes particularly in the annulus fibrosus. In some clinical material Knutsson has been able to show roentgenologically that such abnormal mobility frequently occurs among patients suffering from pain in the lower part of the back. After compiling the above-mentioned clinical material Friberg and Hirsch found a frequency of instability of 15 %. They further found *roentgenological disc degeneration* in 50 % of 4,200 patients. Güntz and Böhmig regard disc degeneration as a pseudoarthrosis in which pains arise in consequence of the abnormal degree of mobility.

As a result of pressure measurements and the registration of the form of the discs Hirsch has observed that ruptures of the annulus lead to an abnormal distribution of pressure in case of mechanical strain.

Whatever clinical or pathological arguments we may produce in support of the idea that annulus ruptures are the direct cause of the pain, we cannot evade the question of whether and how the annulus is innervated. Fick believed that nerve fibres exist in the external parts of annulus fibrosus. Jung and Brunschwig showed that there existed unmyelinated nerve fibres in the long anterior and posterior ligaments as well as between the annulus fibrosus and the spinal ligaments, which however, did *not* enter into the disc itself. Since then Roofe has investigated the innervation of lumbar discs four and five. In his conclusions he says that "many unmyelinated nerve fibres were observed in the annulus fibrosus. The fibres terminated in naked nerve endings *within the disc itself*. The fibres were very fine. In spite of the fact that he did not observe end organs, the type of arborization would indicate that they probably were pain fibres. Ehrenhaft found in a section through a 5½-months-old embryo, stained according to Bodians technique that nerve fibres beneath the anterior ligament gave off fine branches to the periosteal vessels entering the cartilaginous disc substance. Wiberg has also stated that the intervertebral disc is innervated.

As the only illustration which Roofe has published does not look particularly convincing and as, moreover, he and Wiberg are the only writers who have found nerve fibres in the *annulus fibrosus,* further investigations on this point appear to be called for, all the more so, as we have now available an improved and more sensitive technique.

A summary of our recent clinical knowledge on low back pain seems to justify the following conclusions:

1. One or several discs can very often induce through disc puncture identical symptoms by increasing the intra-discal pressure.
2. If the pains are produced, the disc involved shows ruptures in the annulus fibrosus. This can be seen by nucleography.
3. Very often the posterior part of the disc is sensitive to direct local pressure over a very small area.
4. If the annulus is ruptured, the function of the disc is to some extent changed. Disturbances can be demonstrated both clinically and experimentally in autopsies.
5. It is still not clear whether the annulus is innervated or not. It has been suggested that mechanical disturbances have the effect of abnormal stresses on the long ligament, in which nerve endings have been found.

The biology of the intervertebral disc has been a subject of discussion in a previous issue of this journal and will not be dealt with at length here. From the practical clinical point of view it looks as if we might associate the term "low back pain" with certain types of rupture in the annulus fibrosus. The entire problem as to why lesions arise at all in the outer collagenous ring of the intervertebral disc requires for its solution a better knowledge of the elements of which the disc as a whole is built up. The behaviour of the disc–this virtually non-vascular tissue–at different ages cannot as yet be surveyed without a wider understanding of the bio-chemical processes that take place in it. It seems to us, however, that, in spite of our awareness of the limitation of the morphology in this respect, it may be worth while making a closer examination of the histological structure of the annulus fibrosus.

EARLIER INVESTIGATIONS OF THE MORPHOLOGY OF THE ANNULUS FIBROSUS

Notwithstanding the interest in the pathology of the intervertebral discs that has been aroused by all the numerous works published by Schmorl and his pupils Andrae, Beadle, Böhmig, Güntz, Hammerbeck, Hildebrandt, Junghanns, Niedner, Püschel and others, and in which the macroscopic and pathological anatomy of the disc was described afresh in detail, no thorough investigations have been made of the finer structure of the intervertebral tissue elements in normal and pathological conditions, as Schmorl himself had already pointed out in 1932. It is admittedly common knowledge that changes called phenomena of degeneration are surprisingly frequently met with in the intervertebral discs and even in very young individuals (Schmorl), but, as Beadle points out: "Neither the limits nor the causes of these changes can be given with certainty". In 1931 Erdheim published a detailed study on the structure of the adult disc, and in 1938 Schajowicz published the results of a histological investigation of material covering the ages between three and twenty-five years.

Thanks to the discovery of the significance of disc prolapse in the disease of sciatica the interest in the normal and pathological anatomy of the discs has again been stimulated in recent years. Numerous examinations of autopsy material have been carried out by Batts, Horwitz, Coventry, Ghormley and Kernohan, Eckert and Decker, Pais, Lindblom and Friberg and Hirsch. Operatively removed prolapses have been studied by Deucher and Love, Eckert and Decker, Pais and others. These various authors have attempted to explain the mechanism of pain in lumbago by determining where the line of demarcation runs between normal and pathological conditions. It cannot be said that the histological investigations have succeeded so far in elucidating the problem of why an intervertebral disc, although showing structurally any number of changes, could possibly be held responsible for lumbar pains. "There is a growing realization that many features of the syndrome are difficult to understand" (Inman and Saunders 1947).

Practically all investigators seem to be agreed that the regressive changes in the intervertebral disc start in the nucleus. According to Hirsch, no ruptures occur in the annulus without the nucleus showing advanced structural changes. The biological factor that lies behind the structural changes in the nucleus pulposus has been studied by Sylvén, Hirsch, Snellman and Paulsson. It looks as if the bio-chemical processes reflected in the central parts of the disc are closely associated with the metabolism of proteins and of ester-bound polysaccharides. The investigations into the sulphur content of nucleus pulposus in different discs and at different ages support the assumption that the changes in the nucleus pulposus are to a certain extent at any rate, a physiological phenomenon in which all the intervertebral discs of the back are affected to an approximately equivalent degree. But although biologically speaking the nucleus pulposus is an extremely interesting object of study, yet it must be admitted on the basis of our present clinical experiences of low back pain that etiologically and pathogenetically the annulus fibrosus is bound to play a far more important part.

THE AUTHOR'S OWN INVESTIGATIONS

The present paper covers the results of a macro-anatomical, histological and electron-microscopical investigation of the annulus fibrosus of the lumbar intervertebral discs. We have aimed at giving a description of structural variations at different ages. In view of the clinical importance which ruptures of the annulus appear to have in particular, we have subjected discs in which such ruptures have been found to thorough analysis.

MATERIAL AND METHOD OF INVESTIGATION

Our material consists of 120 lumbar backs from autopsies. Out of these, series No. 1 consisting of 105 cases has been X-rayed, whereupon all the five lumbar discs have been cut through *horizontally*. The discs have been photographed and then fixed with formalin. 65 of these, i.e. 325 intervertebral discs, have been microscopically examined. The distribution of this series of 105 backs according to age will be seen from fig. 1.

Series No. 2 relating to ten cases has been cut sagittally. This series comprises the ages: six months, one year, three, six, nine, twelve, sixteen, eighteen, twenty-four and twenty-five years.

Series No. 3 relating to five cases is derived from the age groups 25–40 years and has been used for the purposes of combined histological and electron-microscopical analysis with special reference to the presence of nerve fibres.

In all three series the discs have been carefully examined macroscopically, particularly with reference to the existence of lesions in the annulus fibrosus. The localization and extent of the ruptures have been registered.

HISTOLOGICAL TECHNIQUE

In view of the difficulty of obtaining even and entire sections with a microtome, since the intervertebral disc in adults is not easy to cut, in series No. 1 each intervertebral disc was divided sagittally,

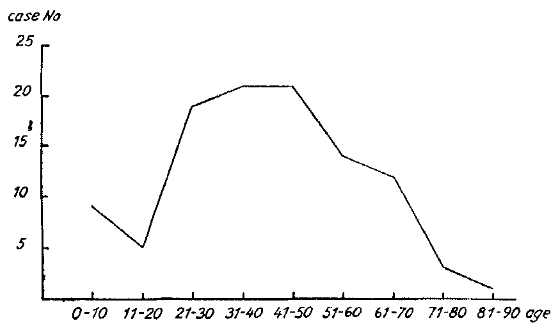


Fig. 1.
Age distribution of series no. 1.

through the middle into two halves one left and one right portion and these were sectioned frontally. Thus each disc was divided into four parts. The preparations were then fixed in 10 % formalin. Furthermore, certain discs were passed through Parengi's fluid (Alcohol 95 % 150 cc., Acid. cromic. 0.5 % 150 cc. and Acid. nitric. 10 % 200 cc.) for a brief period. By this means it was possible to avoid calcified or ossified parts in a disc obstructing the microscopical section. This material was embedded in paraffin and was stained with hematoxylin-eosin according to van Gieson. Further, on a portion of the material especially selected from different age groups use was made of Mallory's technique, Laidlaw's silver-staining for reticulin fibres and Weigert's elastin-staining. The same staining procedure was used for series No. 2.

Series No. 3 was fixed in neutral formalin and was then embedded direct in paraffin. In addition to the above-mentioned stainings, Bodian's and Davenport's technique for nerve fibres was also used, and likewise metachromatic staining with toluidin blue for indicating the presence of mucopolysaccharides. That part of this series which was subjected to electron-microscopical examination, was treated in a fresh condition with osmium acid and was then enclosed in a mass of acrylic plastic according to Sjöstrands technique. This part of the investigation was carried out by Sjöstrand.

e
a
b
c

d

Fig. 2.
Sagittal section through the ventral part of the 4th lumbar disc of a 25 year old adult showing the typical lamellation structure of the annulus which is often divided by heavy basophile lines. The directions of the fibres are different in the several adjoining lamellae, and they are often bridged over by a rather dark arched line, the so-called Schmorl's "tension fibre" *a, b, c, d* some small foci of so-called mucous degeneration; *e* lig. long. anterior.

THE NORMAL SHAPE OF THE ANNULUS FIBROSUS

The annulus fibrosus or, as suggested by Schmorl and Junghanns, the annulus lamelosus, consists of a complex system of fibres, fig. 2. These fibres form lamellae or bundles, which macroscopically look as if they have a circular course. The lamellae are of different thicknesses. Between two bundles there sometimes lies a stronger basophile, and sometimes an acidophile strip. Occasionally the lamellae are bridged over by "attachment fibres" running archwise.

A part of the outer lamellae of the annulus is connected by means of a preparatory calcified zone with the marginal bone edge, fig. 3. We are able here to confirm Erdheim's observations.

The outermost lamellae run an oblique course both upwards and downwards from one vertebra to the other in the direction of the long ligaments, which in their turn represent a continuation of the periosteum of the vertebral bodies (Erdheim). A small portion of the lamellae, turning round the vertebral border, passes direct into the perio-

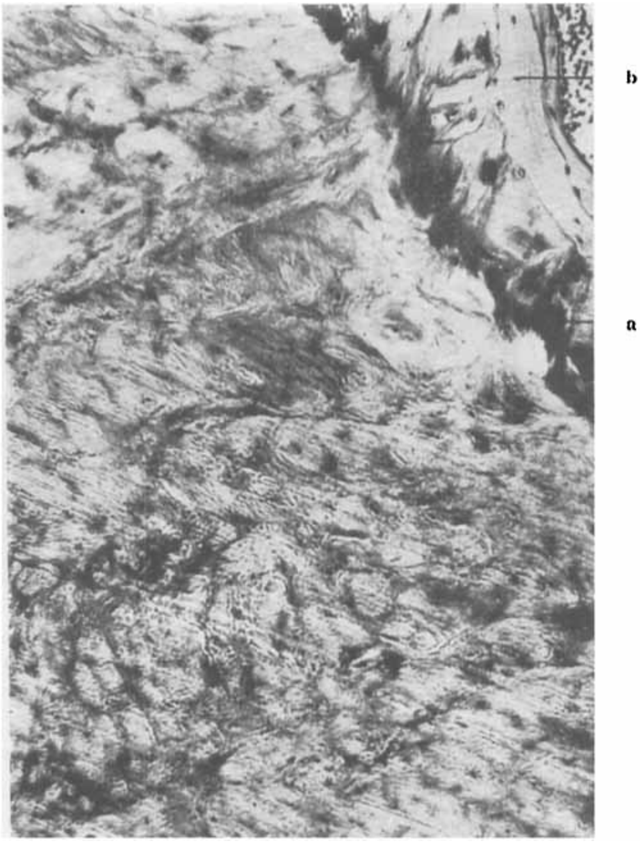


Fig. 3.
The joining of the annulus to the bone *b* of the marginal edge by means of a preparatory calcareous layer *a*. Only very few fibres penetrate into the bone as so-called Sharpey's fibres.–The typical fibrous cartilage and the lamellous structure of the annulus in that part can be seen (25 year old adult).

steum of the vertebral bodies and thus contributes towards a firm fixation of the disc and bone system.

The inner and the largest part of the annulus runs obliquely in towards the cartilaginous plate and the vertebral body and becomes attached thereto. The nearer one approaches the nucleus, the more horizontally run the bundles of fibres in towards the plate. Frequently, especially in the interior of the annulus, the lamellae do not invariably run a regular course, so that the line of demarcation between them and the nucleus pulposus may be difficult to determine.

Each fascicle has its own fibres, which usually retain a definite direction within the same fascicle. If we compare the fascicles with one another we find that the reciprocal arrangement of the fibrillae alter-

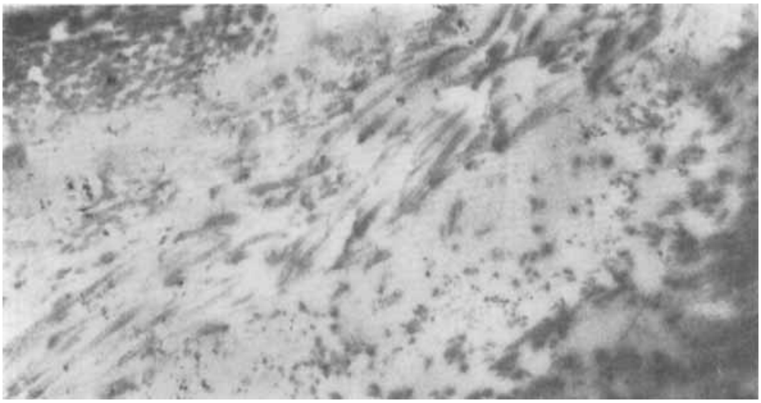


Fig. 4.
Electron-microscopical picture of the annulus fibrosus.

nates between vertical and circular, oblique and arciform without any system or any given rule being discoverable. In the sections one frequently sees a parquetry pattern.

The annulus fibrosus is built up of a collagenous system, as is very clearly shown in electron-microscopical pictures, fig. 4. Groups of collagenous fibres run in layers in the same direction; a closely adjacent group follows a different direction–pictures, that is to say, which in regard to the structural arrangement give the same impression as is obtained from examinations in which an ordinary histological technique is used.

The normal annulus fibrosus is basophile, the strongest degree of stainability being close to the nucleus pulposus and in those places where the annulus is attached to the cartilaginous plate or the vertebral body, as the case may be. The basophilia diminish rapidly towards the outer parts of the disc, in the long ligaments passing into acidophilia. With eosin the ligament stains red like pure collagen. On the borderline between these two elements we find in the slightly basophile-stainable annulus pure acidophile transverse or longitudinal bundles of fibres containing distinct cells of connective tissue. This transitional zone represents in young children an appositional place for the formation of annulus lamellae. Erdheim's proposal to call the long ligaments the perichondrium would appear to be histologically justified. In the strongest basophile zones, i.e. closest to the bone and the cartilaginous plate, the cells in the annulus fibrosus are large, circular or oval. They have a distinct capsule and are frequently surrounded by a dark-blue zone. The nuclei are small and rich in chromatin. It is thus a question of *typical cartilaginous cells*. The cells become considerably

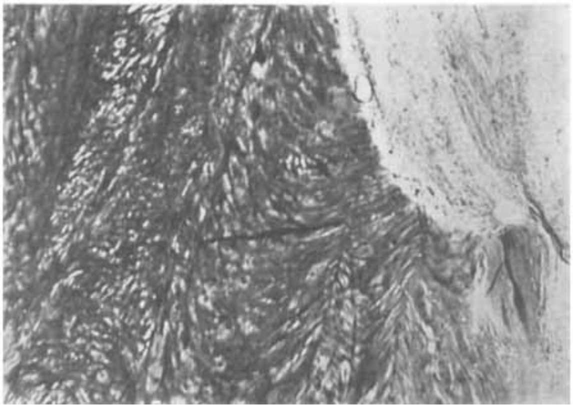


Fig. 5.
The border between the annulus fibrous and the post. long ligament. Stained metachromatically with toluidine blue. *a* annulus, *b* ligament.

smaller and flattened towards the interior of the disc. Towards the greatest convexity of the annulus they lose their capsule, and where they lie close to the ligament they assume the character of pure connective cells.

In metachromatic staining with toluidin blue we observe that the strongest basophile zones have a more distinct metachromatic colour, whereas the outer areas consisting of dense collagenous connective tissue–the long ligaments–do not assume a violet colour (fig. 5). But the annulus metachromasia is on the whole less strongly positive than is the case with nucleus pulposus in normal discs. This is offset, according to Lison, Holmgren, Sylvén, Hirsch and others, by a lower content of high-molecular ester sulphates. Some authors (Coventry, Ghormley and Kernohan, Pais) were unable to induce in their preparations any polysaccharide reaction in the nucleus. This may perhaps be explained by their having worked with autopsy material that was not fresh and which, moreover, had been treated for the purpose of decalcification with strong acids. Cartilage treated in this way gives no positive mucous stain. Meyer, Sylvén, Hirsch, Snellman and Paulsson have been able to show that the nucleus pulposus has a very high content of high-molecular ester sulphates.

The annulus fibrosus presents essential differences within the same lumbar disc.

Ventral and lateral parts are similar in appearance, and the dorsal parts differ from the rest. (Fig. 6.) Dorsally, the annulus is first and foremost much narrower, the number of lamellae is fewer approximately half the number of those situated ventrally, where it is possible

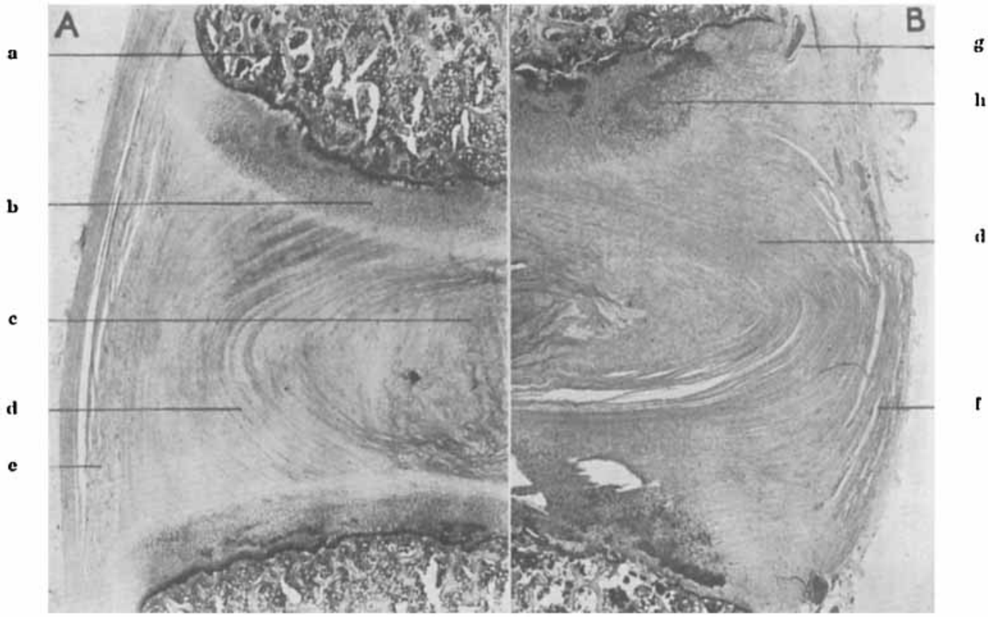


Fig. 6.

A. Sagittal section of the ventral part of the lumbar disc of one aged 14.–*a* bone, *b* cartilaginous plate, *c* nucl. pulp. not distinctly limited from the annulus, *d*, which possesses numerous distinct lamellae describing a flatly convex arch towards the opposite cartilaginous plate and partly entering the ventral longitudinal ligament (perichondrium) *e*.

B. Dorsal part of the disc of the same case. The annulus *d*. is thinner, the lamellation is less distinct and the connection with the dorsal long ligament which is thinner and more dissolved, is not so firm; *g* vessels in the lig. which penetrate only towards the calcified marginal epiphysis *h*.

to distinguish microscopically 15–20 lamellae. Furthermore, the lamellae are often narrower and their arrangement in fascicles or bundles is not equally distinct. The fibres in the individual lamellae frequently run parallel with one another without the demarcating blueish fibre between them.

Another important difference between the ventral and the dorsal part of the annulus is the relation to the long ligaments. According to Schmorl and Junghanns, the ventral ligament is firmly attached to the vertebral bodies at a point where at the same time it forms the periosteum. Its connection with the intervertebral disc is loose, and here the ligament is far thinner. Further, according to the same authors the ventral ligament contains fewer elastic fibres. The posterior ligament is said to be much thicker and is more firmly attached to the

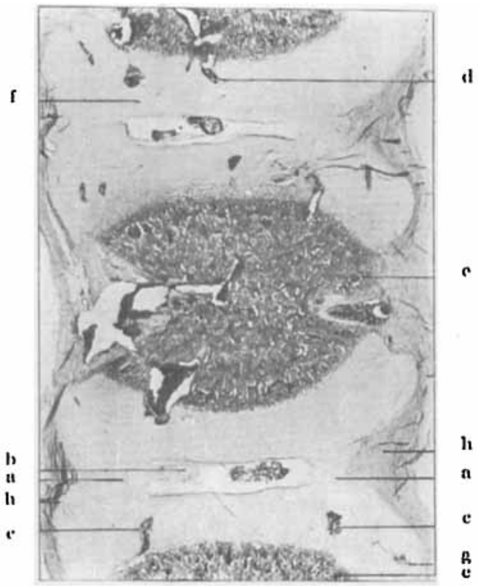


Fig. 7.

Sagittal section from a 7 months' (25 cm sitting height) fetus. The annulus lamellosus *a,a'* is distinctly developed and can be distinguished from the nucl. pulp. *b*; *c,c'* marginal peripherical vessels and *d* central axial vessels penetrating into the cartilaginous plate *f* from the marrow *e*; *g* perichondrial vessels and *h,h'* lig. longitudinal.

disc. According to Fick, moreover, the posterior ligament contains a greater number of elastic fibres.

In contrast to these authors we have found that both macroscopically and microscopically the ventral ligament consists of fairly thick and more firmly constructed dense fibrous connective tissue in close union with the annulus, the external fibres of which partially radiate into this ligament, as we have described above. The posterior ligament, on the other hand, is thinner and consists only of a series of fanlike bands, which are not particularly firmly attached to the disc. Our observations are in agreement with Beadle's, who moreover believes that these differences might have far-reaching consequences in conditions involving trauma to the intervertebral discs.

With elastin staining according to Weigert we have only been able to observe isolated elastic fibres in the posterior ligament and, unlike Fick, none at all in the actual annulus tissue.

In our opinion the annulus is not composed of fibrous and elastic lamellae with an occasional cartilaginous cell, as Inman and Saunders affirm.

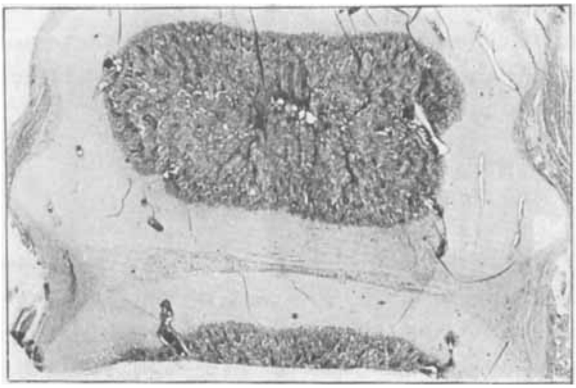


Fig. 8.
New born. The same arrangements of the vessels are seen as in fig. 7.

THE BLOOD SUPPLY OF THE DISC

The blood supply has previously been thoroughly studied by Übermuth, Böhmig and Schajowicz. In embryos, in addition to a central axial vessel, which runs vertically from the osseous vertebra to the cartilaginous plate, there enter regularly two further ventral and dorsal vessels, the so-called marginal vessels (Figs. 7 and 8).

These vessels emanate from the cancellous bone of the vertebral bodies and run obliquely through the disc to the latter's centre. Between the individual marginal vessels from the same side there are, according to Übermuth, anastomoses and, moreover, the marginal vessels have connections with the perichondrial network of vessels through small arcades (vascular arches). However, these blood vessels enter neither into the centre of the disc to what subsequently becomes the nucleus pulposus, nor into the annulus fibrosus. That is to say, these vessels do not come into connection with those in the other vertebral bodies. Vascular connections between different vertebrae are only to be found in the long ligaments. All these vessels are obliterated at an early stage, leaving scars in the cartilaginous plates. This process is terminated at the same time as the growth ceases, i.e. at about the age of twenty. *Thus, the nucleus pulposus and the annulus fibrosus are completely without vessels during every phase of the individual's life,* if we disregard small isolated and insignificant branches which enter from the perichondrium into the calcified marginal epiphyses, as may be seen at about the time when these areas begin to ossify. Ventrally, this begins at the age of 13–14 (Mau, Schajowicz). When these epiphyses finish forming (at the age of 20), these vessels also disappear, sometimes leaving small scars. *After the cessation of growth the annulus fibrosus becomes entirely free of vessels.* There are a few small vessels in the outermost layers of the ligaments, but these vessels never penetrate into the annulus.

THE NERVE SUPPLY

It has not been definitely elucidated whether the annulus fibrosus is supplied with nerves at all. Previous investigations were discussed on page 187. Our investigation is based on fresh autopsy material, cut after having been embedded in paraffin and stained according to Bodian's and Davenport's techniques, series No. 3. We have been able to observe fairly large bundles of nerve fibres outside the ventral and still more frequently outside the dorsal ligaments. These bundles have given off thinner bundles, which have accompanied the vessels, and which we have been able to follow a short way obliquely into the outermost parts of the ligaments. We have never succeeded in following them to the borderline between ligament and annulus and still less into the annulus. But the histological technique in regard to nerve fibres is very uncertain, and a negative find does not necessarily mean that nerve fibres cannot be discovered. Continued investigations using a better and a more sensitive technique are necessary. We have therefore been engaged, in collaboration with Sjöstrand, on electron-microscopical studies, to which we hope to revert later on.

STRUCTURAL CHANGES IN THE ANNULUS AT DIFFERENT AGES

Unlike Übermuth, who believes that the annulus fibrosus is not present in intra-uterine life, and that at six months–a period at which the spine is beginning to be used as a support for the body in a vertical position–there is a ring of fibrous cartilage round the nucleus, we have observed in a seven-months-old foetus (sitting height 25 cm.) that the annulus fibrosus was well developed (Fig. 7). Pais has published a picture of an eighteen-weeks-old foetus (sitting height 16 cm) with annulus lamellae, and Ehrenhaft has described in a 5½ months old (19 cm) very well developed fibres of the annulus.

During the intra-uterine life and before the upright position begins, the nucleus pulposus lies in the middle of the disc. Not until later does it shift in the lumbar spine posteriorly, and at the same time the annulus becomes narrower in its dorsal than in its ventral portion.

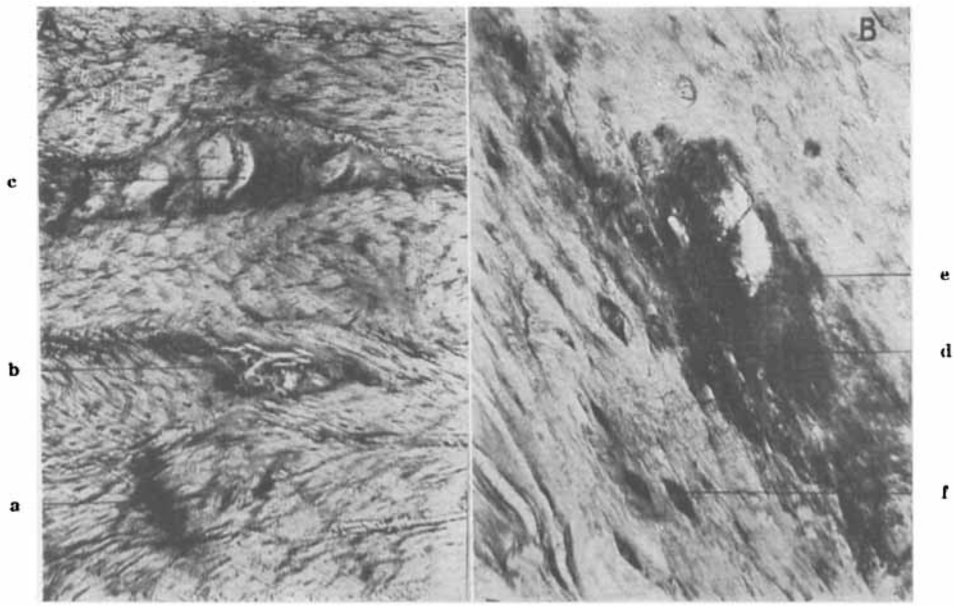


Fig. 9.

Horizontal section of the 4th lumbar disc of a 46 year old adult (case 49). *A.* By higher magnification it is possible to observe the lamellous structure, the different paths of the fibres of the adjoining compartments, and very often also a dark line between them or a tension fibre *a*; stray seats of so-called mucous degeneration with the commencing formation of cavities, *b,c*.

B. A vigorous basophylic focus of so-called mucous degeneration *d*, in the area of which the fibrous structure has mostly disappeared. At *e* the precipitation of very small grains can be observed. The cartilage cells in the vicinity show thick, dark blue, i.e. strongly basophyle sites *f*.

During the years of growth the annulus fairly soon acquires a compact massive structure partly through appositional growth via the perichondrium and partly through interstitial formation. At the age of twenty-five this definitive shaping of the annulus is terminated and the annulus becomes firmly anchored partly to the cartilaginous plate and partly to the marginal border of the vertebral bodies.

But long before that, though seldom before the age of fifteen, changes are observable in the annulus. Between the lamellae may be found oval or irregular areas, usually with a concentric course. These "foci" stain dark blue with hematoxylin, i.e. they are more strongly basophile than the surrounding annulus. They may be isolated or may lie several in a row close to one another, sometimes confluent. Within the areas described here it may happen that the normal fibrous structure is in process of disappearing or has already disappeared (Fig. 9).

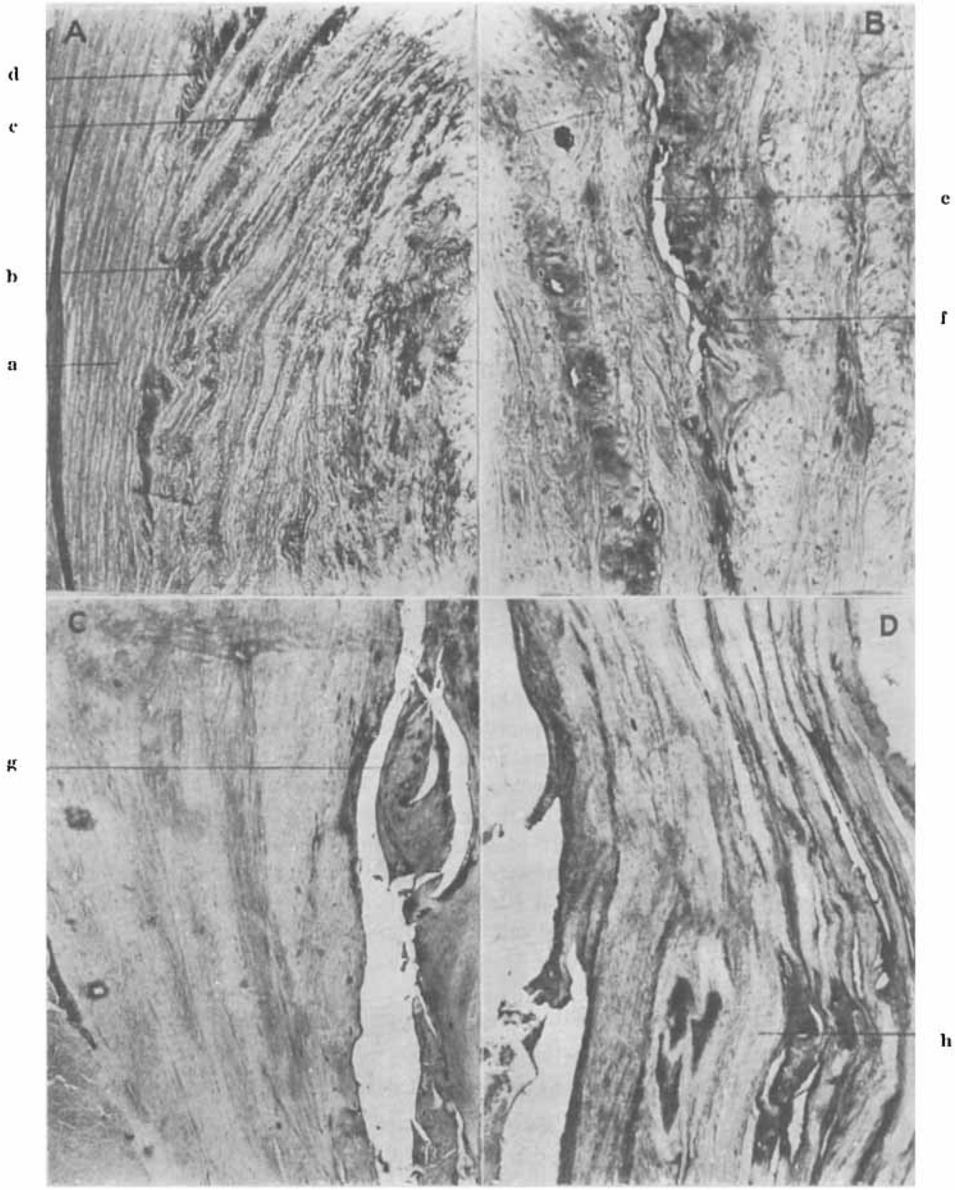


Fig. 10.

A,B,C,D. Horizontal sections, different zones, *A,B* of the ventral part and *C,D* of the dorsal part of the 4th lumbar disc from a 43 year old man (case 2). Different stages of development of the so-called mucous degeneration. In *A* the degenerated seats are situated near the ventral lig. *a*, follow the direction of the lamellae and are more numerous than normal *b,c,d*. In *B* commencing formation of crevices *e* surrounded by proliferation of cartilage cells *f*. C. Larger crevices near the surface with detached mostly necrosed fragments of the annulus *g*. *D* numerous circular degenerations; the normal fibrous structure has partly disappeared, and the lamellae *h* have been hyalinized.

The focus is in that case filled with a mucilaginous, light to dark blue mass. In this way there arise concentric cracks of varying size. It is very seldom that these ruptures, which are more common in the central interior parts of the annulus, reach as far as the periphery. Occasionally one finds fibronoid masses or a proliferation of cartilaginous cells in the wall of these cracks, evidence that it is here a question of intravital structures and that they are not artifacts (Fig. 10). These cracks are more common in the posterior part of the annulus than in the anterior or lateral parts. Apparently they do not communicate with the nucleus pulposus and in that way differ from the radial cracks, which will be described later. They may, however, show ramifications and thus intrude upon the structure of the annulus.

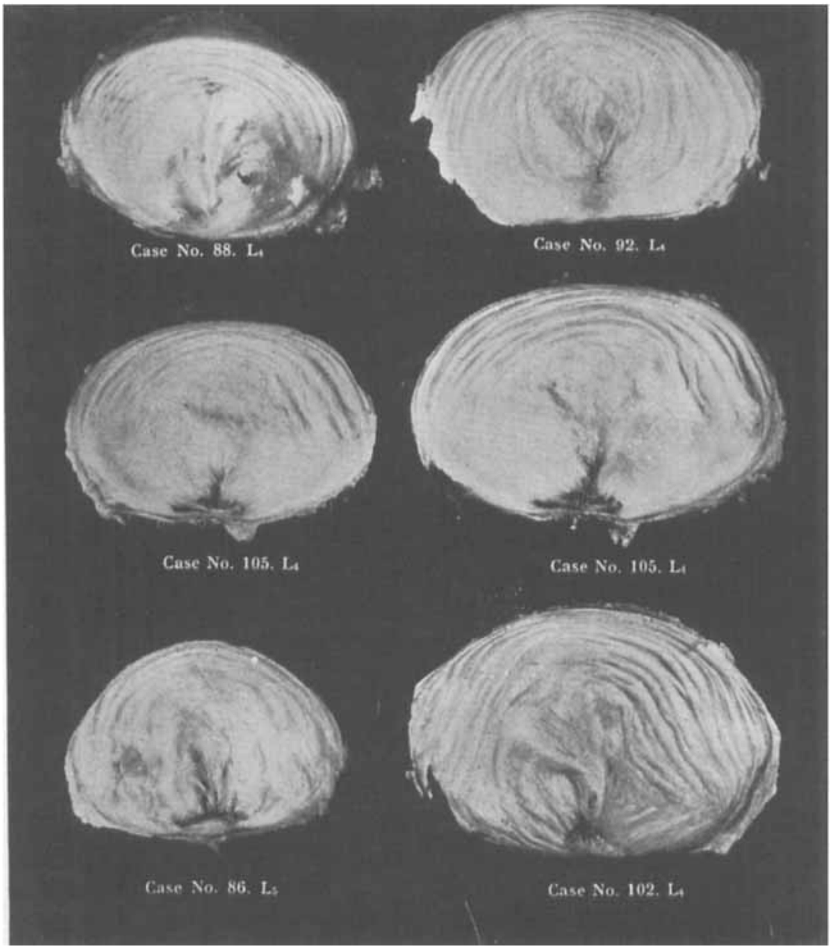
In metachromatic staining with toluidin blue we have been able to observe that a part of the focus, or more generally the whole of it, does not show any positive reaction. We know that the collagenous fibres are connected with one another by a highly polymerized complex mucopolysaccharide cementing material, which probably is not only highly important for the nutrition of this non-vascular tissue but is also essential for giving the annulus its physical properties–those of an elastic firm "materia". In depolymerization, i.e. the breakingdown of the polysaccharides due to physiological or pathological causes, there is therefore reason to expect a deterioration of the tissue. As far back as in 1931, when our knowledge of the biochemistry of connective tissue was still very slight, Erdheim wrote in explanation of the granular-albumoid degeneration that takes place in the nucleus pulposus: "it is possible that a chemical decomposition of the cementing material of the cartilage takes place, in the course of which the connection between the chondroitin sulphuric acid and protein is dissolved". The foci or cracks just described are found to exist quite frequently after the age of fifteen. They are then, however, not very widespread and are isolated phenomena. They become more common after the age of twenty-five. They may merge together into larger cracks or cavities, and after the age of thirty it is seldom that one finds the fourth or fifth lumbar disc without such cracks having formed, while at the same time the other lumbar discs in the same individual are still entirely without such changes. It is only when they lie near the surface or become numerous or more widespread that there arises a weakening of the firm annulus ring.

After the age of twenty numerous other changes are observed in addition to those just described, and as age advances these changes occur with increasing frequency. The fibrous structure of the lamellae can become homogenized or hyalinized. Further, the arrangement of the fibrillae alters, while at the same time they become more frequently fragmented. The lamellae stain irregularly and lose their basophilia. After the age of forty one frequently observes hyalinized zones in which lie cartilaginous cells isolated, or in groups. These cells have a distinct capsule with a dark blue and sometimes calcified enclosure. After the age of fifty it is not infrequently seen that vessels and undifferentiated connective tissue that has emerged from the bone marrow of adjacent vertebral bodies or from the long ligaments have penetrated into the cartilaginous foci. This initiates the ossification of the latter. In such cases, however, the *entire* intervertebral disc already begins to show severe degenerative changes.

RADIATING RUPTURES IN THE ANNULUS FIBROSUS

The whole of our material of *horizontally* cut lumbar intervertebral discs comprises 550 distributed over different ages. Already when making our macroscopical examination we were able to establish with a very high degree of frequency that the lamellae of the annulus ruptured not only concentrically, as has been described above, but also radially in a direction from the nucleus out towards the periphery. The ruptures could be of different scope, i.e. a different number of annulus fibres were involved. Sometimes only a few and sometimes the entire number were ragged. This is no new observation. Schmorl and his school have published pictures of changes of this kind, Lindblom has frequently spoken of them, and Friberg and Hirsch have shown that the changes within the lower lumbar discs are most frequent posteriorly, whereas higher up in the lumbar spine they are more irregularly distributed, not infrequently localized ventrally. The latter authors have further pointed out that the ruptures invariably start from inside the nucleus, i.e. the most centrally situated fibrillae break first, after which follow ruptures in lamellae situated nearer the periphery. When a system of lamellae breaks, the fibrillae around the ruptured area change direction. Probably owing to the conditions of tension inside the disc, the fibres deviate out towards the periphery, so that finally, when a sufficient number of fibres have snapped, there arises a bulbous structure on the disc. Lindblom, Friberg and Hirsch attach great clinical importance to these ruptures, and the two latter authors have gone so far as to believe that they should be able to identify clinical degeneration of the disc, i.e. disc degeneration with clinical symptoms of radiating ruptures in the annulus. In other words, a disc degeneration does not acquire clinical importance until a sufficient number of fibres ruptured radially in the manner indicated above have so weak-

Case No. 98. L_4 (Normal)



Case No. 88. L_4

Case No. 92. L_4

Case No. 105. L_4

Case No. 105. L_4

Case No. 86. L_5

Case No. 102. L_4

Fig. 11.
Posteriorly radiating ruptures.

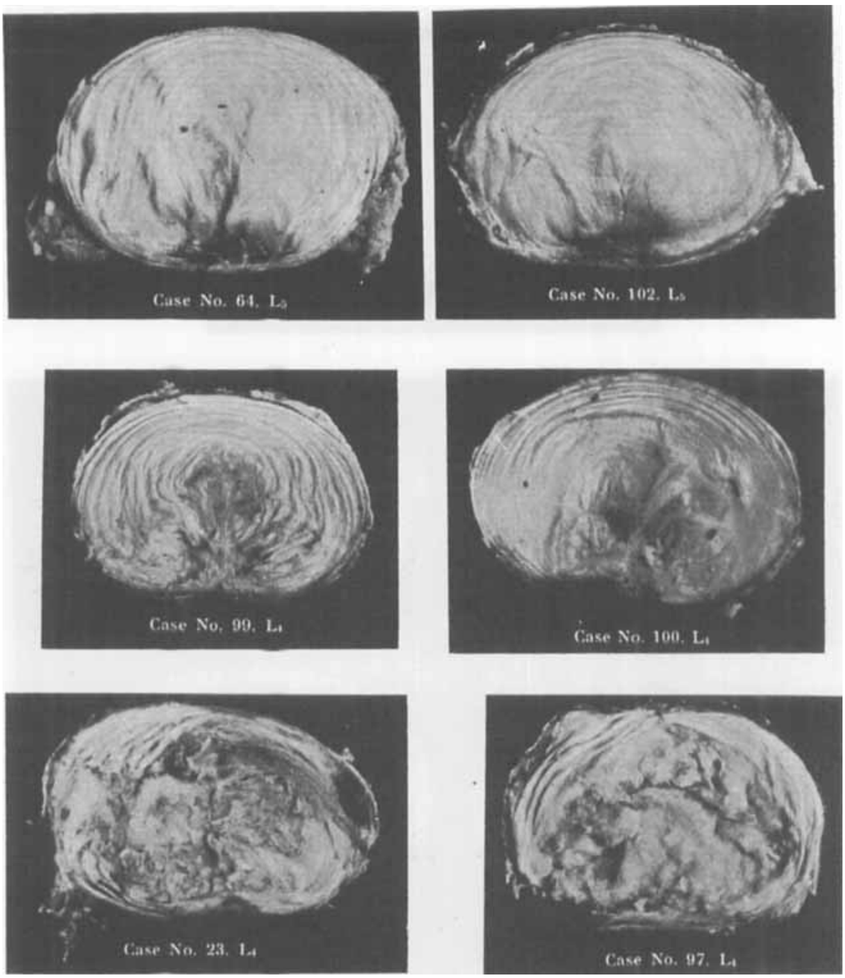


Fig. 12.
Posteriorly radiating ruptures.

ened the physical properties of the entire intervertebral disc that abnormal mobility frequently arises between adjacent vertebrae. Upon a mechanical investigation of the autopsy material they found that the instability demonstrated roentgenologically by Knutsson was due to radiating annulus ruptures within the posterior portion of the intervertebral disc. These ruptures weakened the posterior "barrier" of the entire disc. Further, upon measuring the changes in shape that arose in intervertebral discs when exerting mechanical pressure on autopsy material Hirsch was able to show that these changes were more irre-

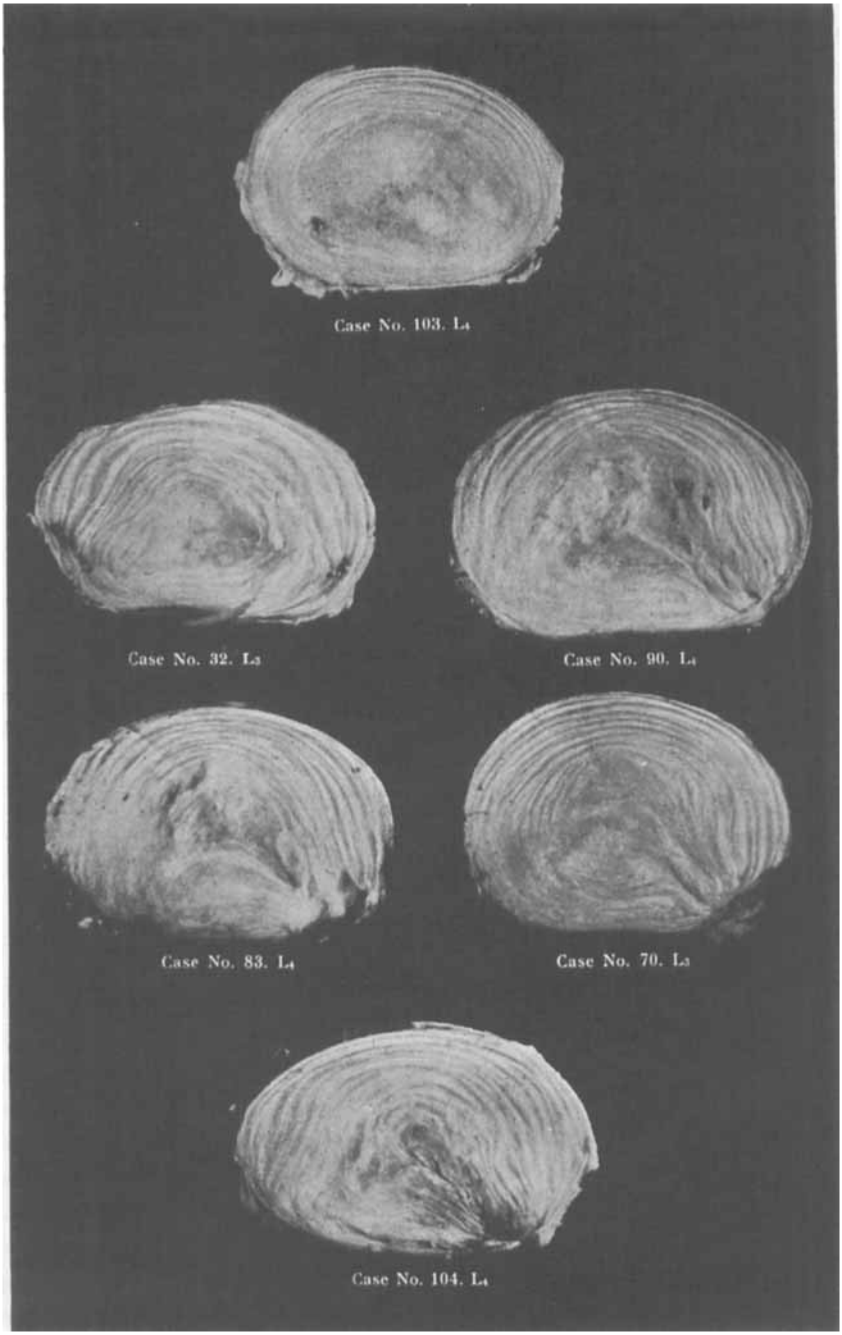


Fig. 13.
Radiating ruptures through the postero-lateral part of the annulus fibrosus.

gular if there were ruptures in the annulus. There was thus reason to assume that radial ruptures disturbed the normal function of the lumbar spine to a far higher degree than other regressive changes in the intervertebral disc, and they may therefore conceivably be of clinical importance.

By tabulating all the radiating ruptures which we came across we were able to confirm Friberg's and Hirsch's observations on the subjects of localization and distribution in regard to both the frequency in different lumbar discs and the occurrence within a given disc. On fig. 11–13 we have shown the most common types which we have found, graded according to the degree of severity exhibited by the radiating rupture. Within the two or three lower interspaces the rupture is seen either sagittally in the median plane or more laterally in the direction of the foramen intervertebrale.

Very frequently the area in and around the crack was more or less of pale red colour, somewhat as if there had been fresh bleeding. These "bleedings" were difficult to explain as generally the patients had been bedridden for a lengthy period before their death and the case histories very seldom gave any particulars of pains in the back suffered at the time or recently relieved. On the other hand it appeared from the carefully kept anamnesis in the clinic that several of the patients who subsequently died stated that they had suffered from pains in the back earlier in life.

THE HISTOLOGICAL PICTURE OF THE RADIATING RUPTURE

The radiating rupture occurs in places where the annulus fibrosus has been so damaged by strong regressive changes that its resistance to rupture and its elasticity have been severely weakened. We have previously described in this paper how ordinary structural changes take place within the lamellar system of the annulus. If we consider that these more or less physiological changes not only become more frequent as age advances but are also discovered more often in the lower lumbar discs than in the upper ones, we cannot avoid the assumption that mechanical forces are bound to play some part in the resistance to rupture of the annulus fibrosus. It seems to us, therefore, that we have still stronger reasons for assuming that the radiating ruptures must be a consequence of mechanical pressures. A change in the lamellar system that has already taken place at a certain age owing to a non-recurrent trauma or an oft-repeated strain is bound to lead to a rupture of the lamellae. Nor does the anatomical localization

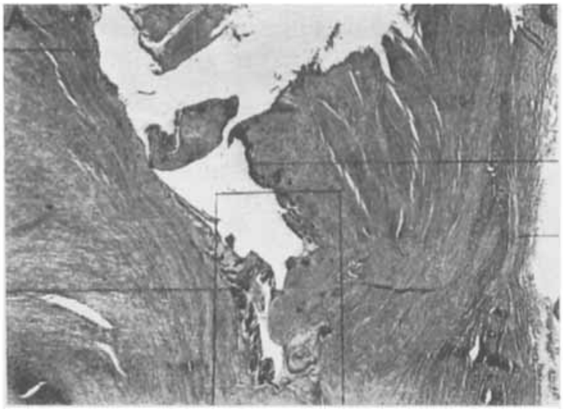


Fig. 14.
Horizontal section of the dorsal part of the 5th lumbar disc from a 30 year old adult (case 11).

A. A large, irregular, chiefly radial crack of the annulus reaching to the lig. *a* and for the greatest part having its walls lined with a connective tissue rich in vessels *b,c,d.*

of the cracks controvert the assumption that this may be the case where the lordosis is most marked; there lie the radial ruptures dorsal. Lindblom has recently given splendid experimental support to this view. By placing rats' tails in a highly bent position and fixing them in that position he was able to induce radiating ruptures agreeing in appearance with what we observe in man.

When the rupture reaches out towards the long ligament, which according to the above description is for various reasons far more common in the posterior part of the lumbar disc, a certain vascular connective-tissue reaction is observable histologically in and around the radial rupture. From the peridiscal tissue there starts a certain "healing" process. An undifferentiated connective tissue grows inside the crack formations in the annulus. At first this tissue, which is extraneous to the annulus, lies quite freely in relation to the ragged lamellae, subsequently entirely filling up the radiating rupture and bridging the gap between the lamellae. Initially this tissue has the character of a porous tissue abounding in capillaries and precapillaries, also in connective tissue cells. Subsequently it becomes a dense, firm and fibrous cicatricial tissue poor in cells or develops into a primitive irregular fibrous cartilage.

In this way minor crack formations or parts of large ruptures may heal with scars (Fig. 20).

If the radiating rupture is large and if the vertebral disc is, on the

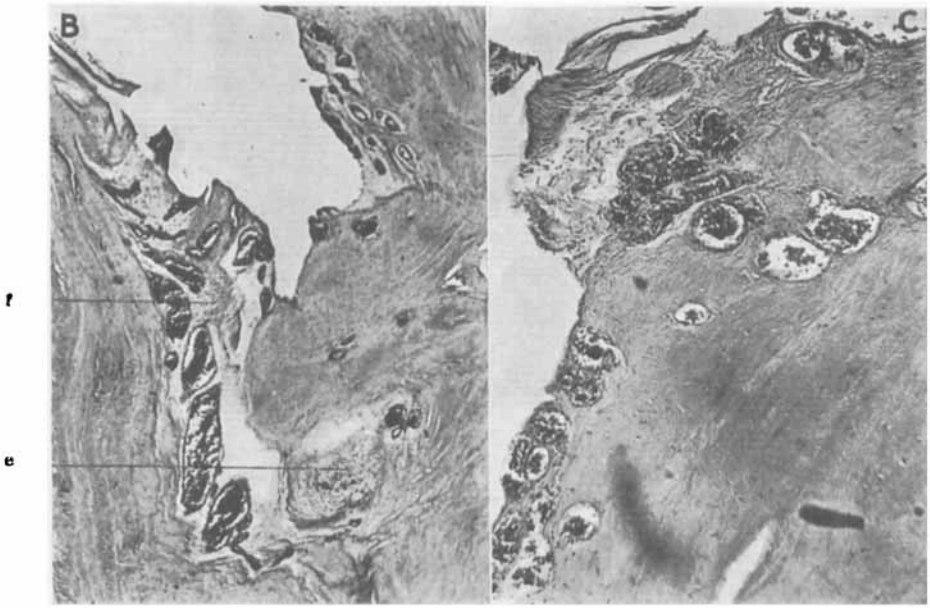


Fig. 14.

B. The framed zone of the preceding figure at higher magnification. Numerous swelled, filled, chiefly capillary vessels in a connective tissue partly young and loose *e* and partly somewhat richer in fibers *f*.

C. An other place of the interior surface of the crack showing the connective tissue rich in vessels.

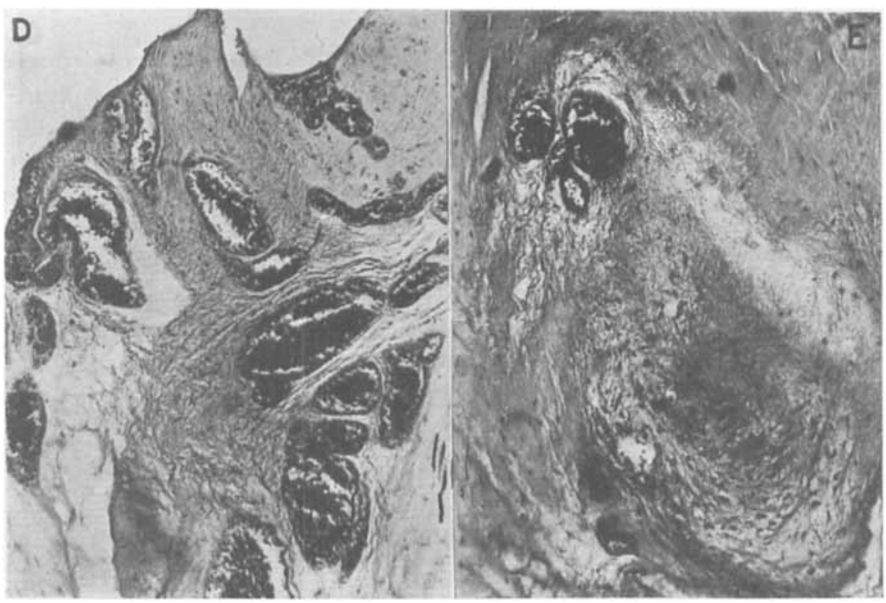


Fig. 14.

D. The zone *f* of the preceding picture B at higher magnification.

E. The zone *e* of the picture B more highly magnified.

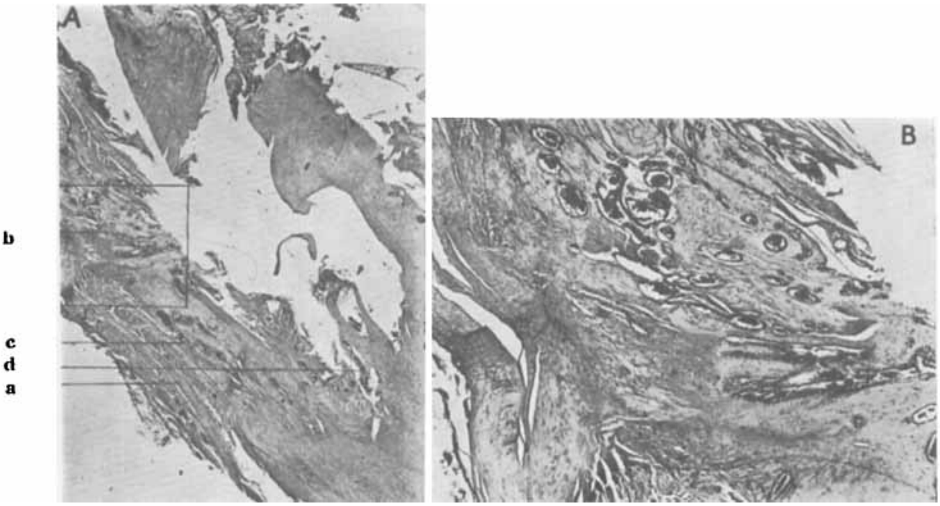
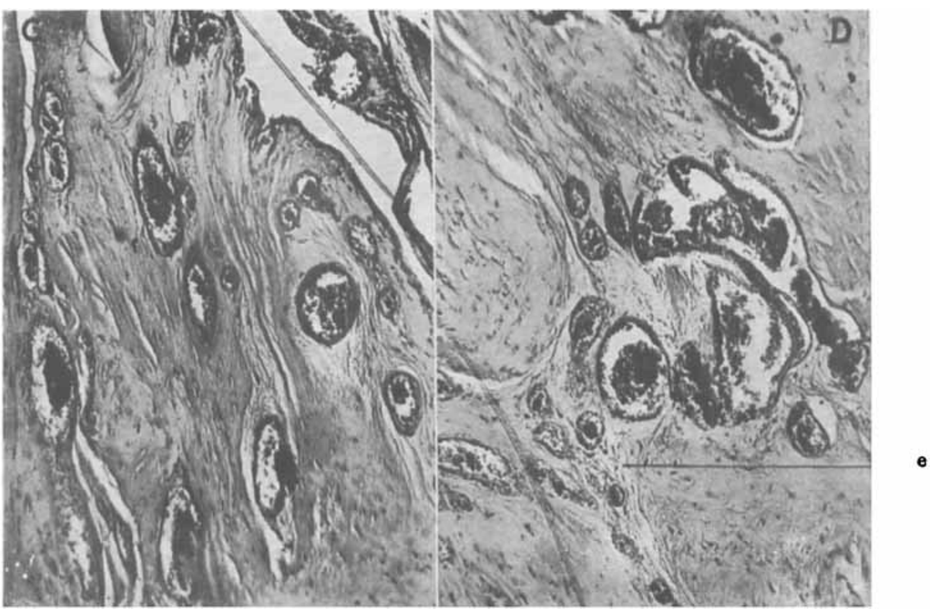


Fig. 15.

Horizontal section through the dorsal part of the 3rd lumbar disc of a 43 year old adult (case 3). Formation of large circular and radial cracks penetrating to the surface of the lig. *a*. From there a connective tissue rich in vessels at *b* and *c* advances towards the crevice partly lining its interior surface *d*.

B. The framed zone *b* of A more highly magnified; it is seen, how the pronouncedly hyperaemic vessels from the outside in an oblique direction run through the crevice.



C,D. The enlarged, hyperaemic, chiefly capillary vessels partly accompanied by loose connective tissue *e*, as seen under a higher magnification.

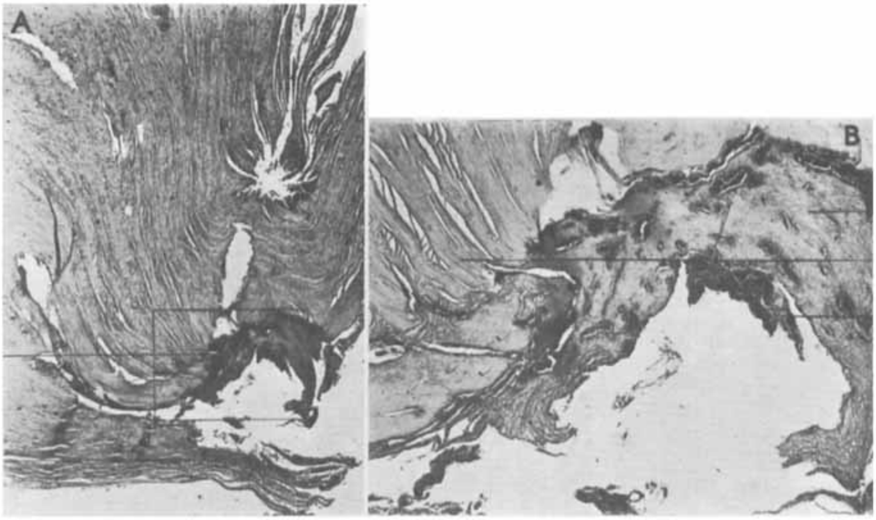


Fig. 16.

Horizontal section of the dorsal part of the 4th lumbar disc of a 30 year old adult (case 13).

A. A radiating rupture in the annulus stretching up to the lig. *a* and for the greatest part lined with a thick irregular layer of connective tissue *b* rich in vessels.

B. The framed zone *A,b* as seen under a higher magnification; the connective tissue has already become very fibrous *c*, but at *d* it is still young and more rich in vessels.

Fig. 17.

Horizontal section of the dorsal part of the 4th lumbar disc of a 43 year old adult (case 3).

Distinct radial and circular formation of fissures partly lined with connective tissue rich in vessels *a,b*. In the section the long lig. is intact, but in another the growing in the oblique direction of vessels *c* can be observed; *d,e* connective tissue rich in vessels partly couvering the interior surface of the rupture.

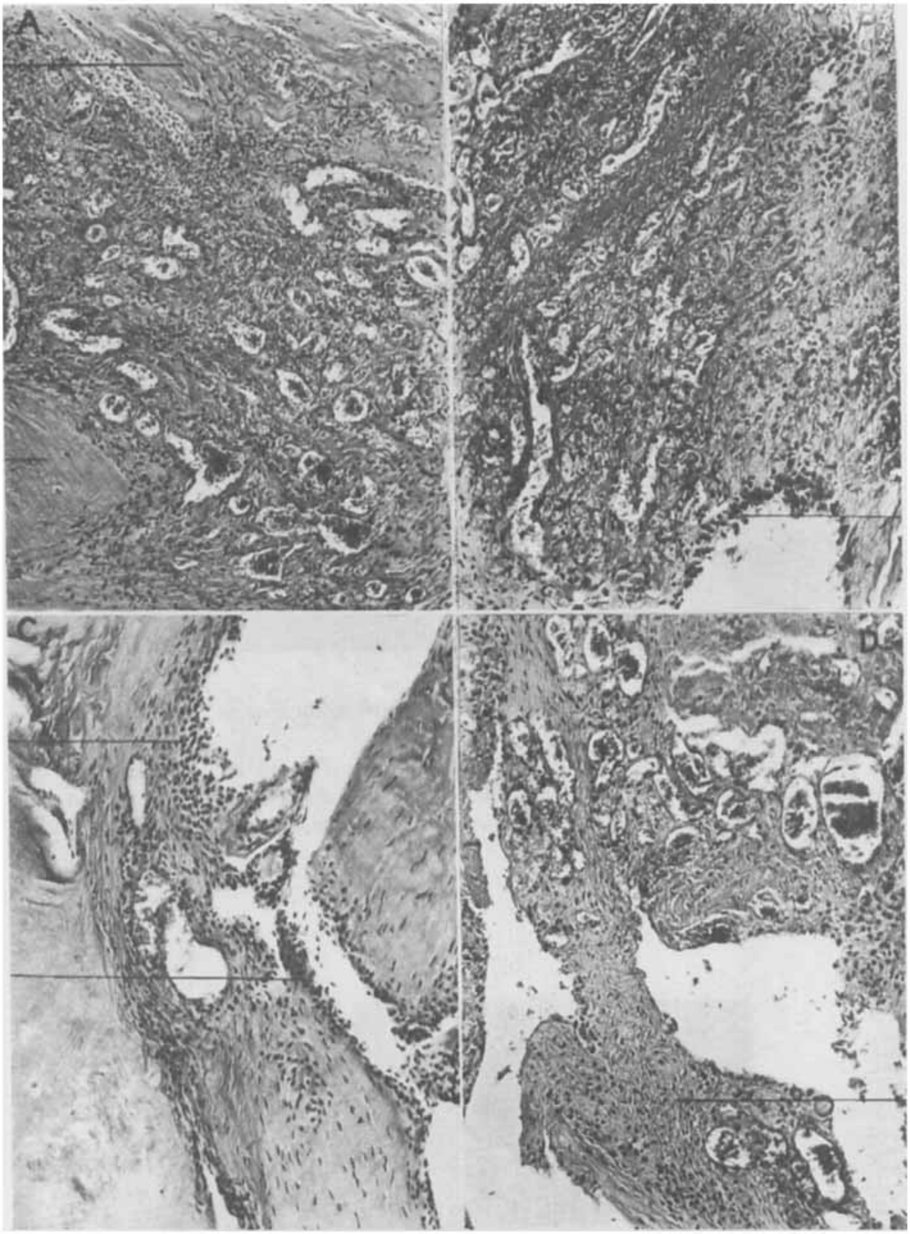


Fig. 18.

Horizontal section of the dorsal part of the 4th lumbar disc of a 51 year old adult. *A,B.* The connective tissue enormously rich in vessels penetrating between the fibres of the annulus, *a, b,* towards the crevice, in an earlier stage of development very rich in cells with young fibroblastic elements and poorly provided with fibres having the appearance of a young indifferentiated connective tissue or granulation tissue; at *c* the fibroblasts line the surface of the crevice like a synovial endothelium.

C,D. At a higher magnification it can be distinctly seen, how the fibroblasts draw across the cavity of the rupture often in several lines *d,e,* and how that tissue like tufts penetrate into the cavity of the rupure *f*.

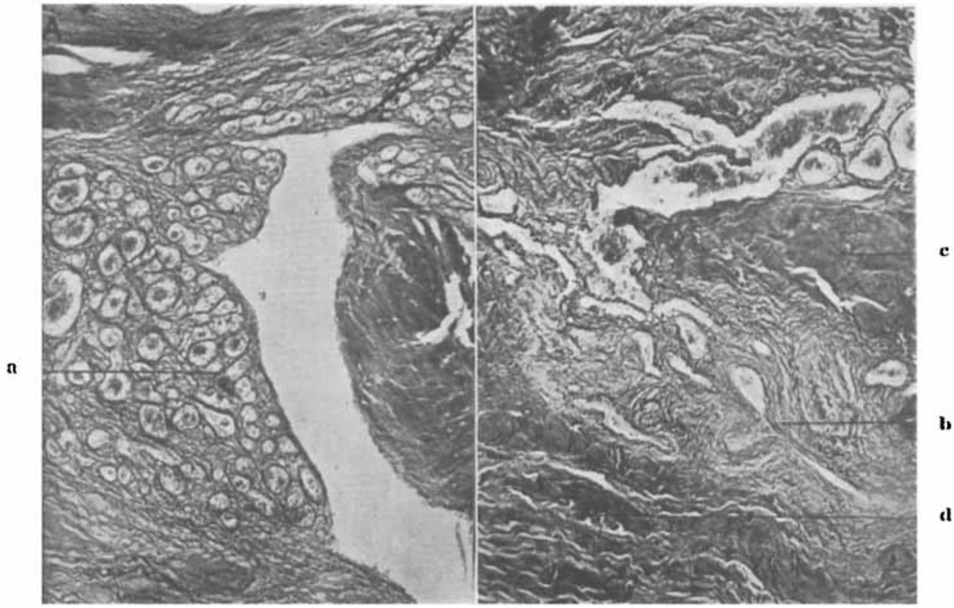
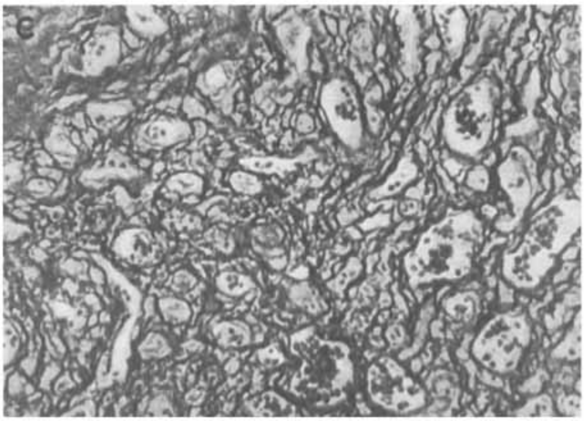


Fig. 19.

The same case as the preceding picture stained according to Laidlaw's silver technique.

A. The tissue enormously rich in vessels and penetrating into the space of the rupture like a plug *a* is richly provided with reticuline fibres. At *B* the advance of this tissue between the collagenous bundles of the annulus, *c*, *d*, can be seen.



C. High magnification in order to show the richness of capillaries and reticuline fibres.

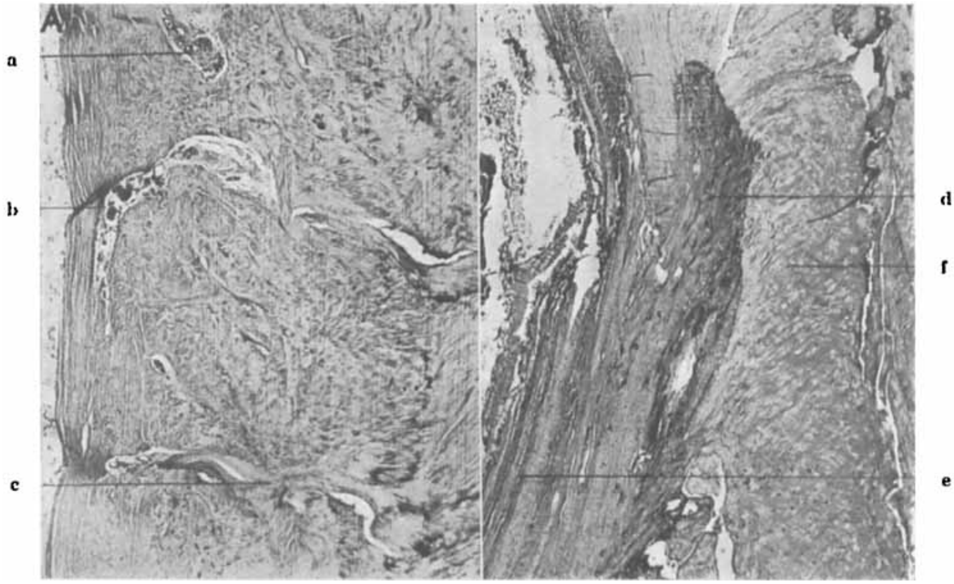


Fig. 20.
Horizontal section through the dorsal part of the third lumbar disc of a 37 year old adult (case 50). *A*. *a,b* vessels penetrating from the outside into the annulus; at *c* a small fissure healed through a scar running vertically in the direction of the annulus lamellae. *B*. Scarrily healed crack in the 4th lumbar disc of a 62 year old adult. The scar *d* rich in fibres but still rather richly provided with vessels radiates from the lig. long. *e* towards the annulus *f*, from whose structure it is clearly distinguishable.

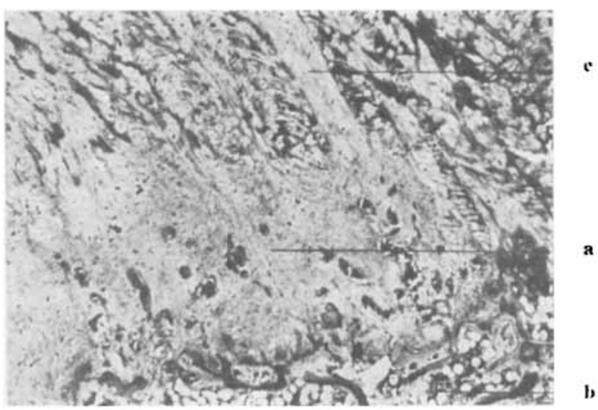


Fig. 21.
Advance of vessels and connective tissue *a* hailing from the medular cavity of the vertebra *b* towards the annulus *c* in a case of spondylosis deformans.

Fig. 22.
Horizontal section of the 5th lumbar disc of a 29 year old adult (case 67). Soft connective tissue very richly provided with vessels and lining the interior surface of the rupture.

whole, fairly well preserved, i.e. still has a certain function to perform, so that the more central parts of the disc become permanently pressed against the periphery, this apparently leads to the forcing apart of the ruptured ends. Those parts of the tissue which border on the crack will therefore be in constant motion, and this is bound to make it difficult or quite impossible for the rupture to be bridged over and closed. That is to say, it cannot heal. But if the radial crack formation is combined with severe degenerative changes in the nucleus pulposus–desiccation and fibrosis–which happens with elderly people, the elasticity and mobility of the intervertebral disc will be greatly reduced. This may possibly be the reason why in such cases one so frequently comes across healed ruptures leaving scars, and it can be observed how the highly vascular connective tissue has been transformed into a firm fibrous tissue with or without the formation of cartilage or of bone.

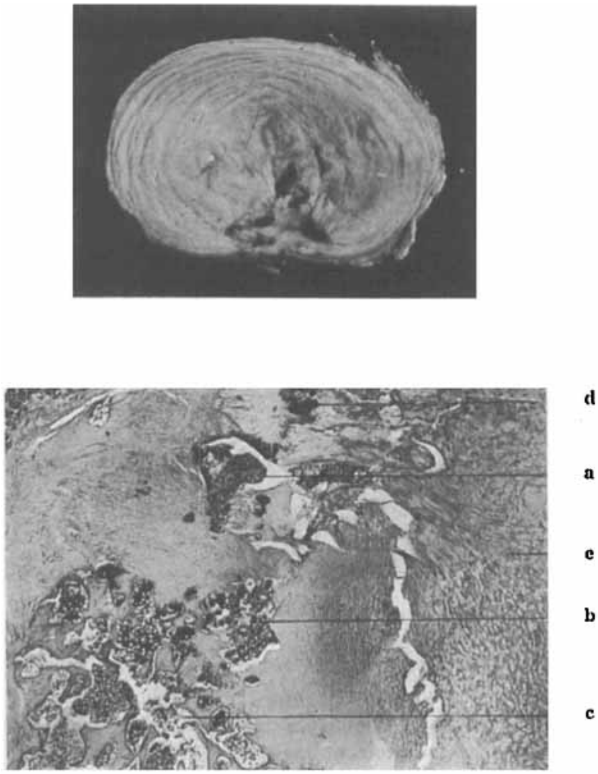


Fig. 23.
Horizontal section of the 4th lumbar disc of a 51 year old adult (case 24). Advanced degeneration of the intervertebral disc with numerous irregular ruptures and cavities. Connective tissue rich in vessels *a,b*, advancing chiefly from the bone marrow *c*, but also from the outside *d*, towards the disc. The rupture cannot be seen in this section; *e* annulus.

The interpretation we have here given to our histological observations is acceptable in view of the knowledge we possess of the clinical course followed by lumbago and the experience that has been gained from taking steps to create stability by way of corsets and operations. Nevertheless the interpretation is tendentious and perhaps too speculative. It is conceivable that other biological factors may account for the fact that healing processes are more frequently met with in elderly people and that the connection between mechanical strain and delayed healing or failure to heal is only apparent.

Even in operatively removed discal ruptures we have been able upon histological examination to observe recent or earlier connective tissue full of vessels in accordance with the development which the radiate

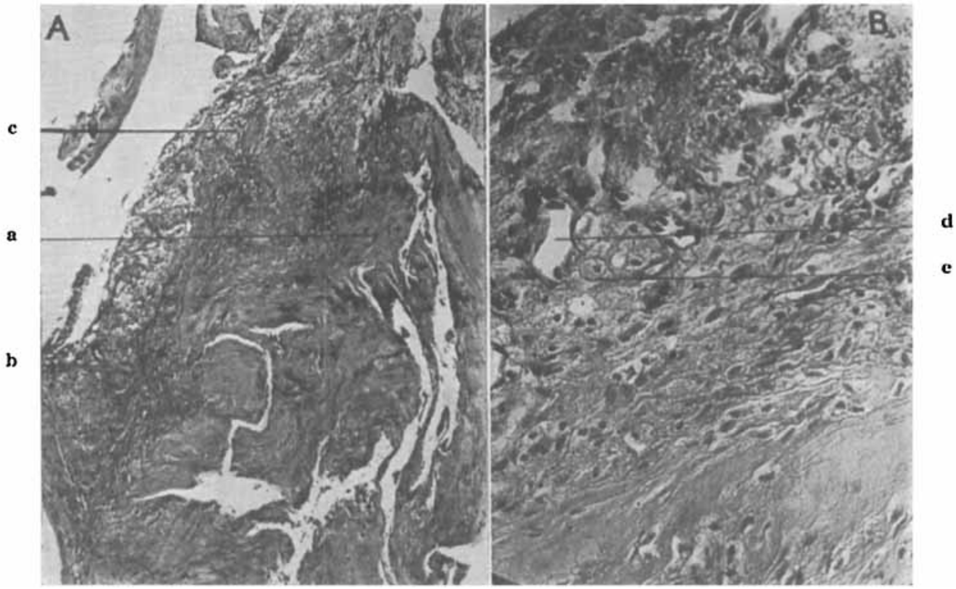


Fig. 24.

Disc prolaps operatively removed from a 35 year old adult.
A. On the surface and between the lamellae of the strongly changed annulus tissue a tissue richly provided with vessels can be seen, which, under higher magnification in *B*, contains capillaries, *d*, connective tissue, some lymphocites, and numerous large cells with clear vacuolar protoplasma *e*. It is the question of phagocytic reticulohistiocytic elements which in this case are probably loaded with fat or glycogene.

ruptures generally present. Thus even in this respect the disc prolapse would appear to be merely a special form of discal degeneration.

We have been able to ascertain, therefore, that radiating ruptures of such a size that they penetrate the greater part of the annulus fibrosus bring about the formation of a connective tissue with an abundance of dilated hyperaemic capillaries which grow into the crack formations. When we see this tissue reaction we may well ask whether it is not precisely this that may explain how it is that the pains to which the radiating ruptures apparently give rise in many cases could be caused by the fact that the highly vascular connective tissue contains nerves. We do not, however, consider ourselves justified at present in drawing that conclusion from our histological investigations. We have not been able to demonstrate the existence of nerve fibres and would not venture for the present to assert that the nerves which in all probability are bound to exist in the vessels may be the pain-producing factor, although admittedly this might very well be the case.

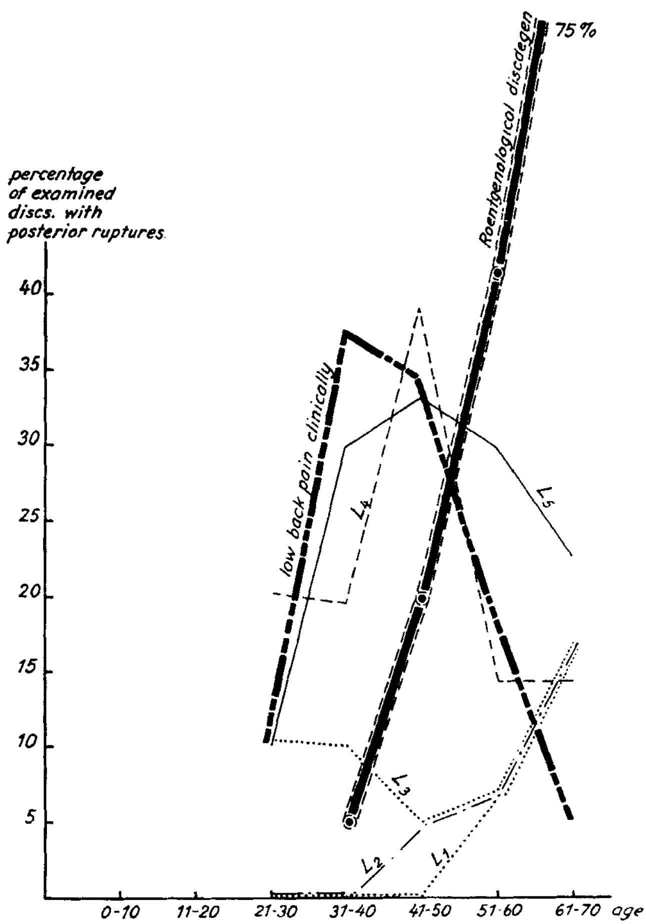


Fig. 25.

The frequency of radiating posterior ruptures in the lumbar region compared with roentgenological disc degeneration and the age distribution of low back pain (see the text).

THE FREQUENCY OF THE RADIATING RUPTURES

In the material from cadavers presented here a count has been made of the frequency of radiating posterior ruptures in all lumbar discs. The number of ruptures met with has been given in percentages of the total number of intervertebral discs examined. We have divided up the cases according to different disc levels and different ages. It will be seen from the diagram that radiating ruptures are far more common within the fourth and fifth lumbar disc than in the others situated higher up. It is also quite evident that they appear at much earlier ages in the fourth and fifth lumbar than in the other discs.

If we estimate the frequency of roentgenological changes in the same autopsy material, i.e. how often it is possible to observe a narrowed interspace, sclerosis and osteophytes, we get a frequency curve corresponding to the thick line drawn in the diagram. X-ray reveals discal changes far later than what corresponds to the true anatomical and, in a still higher degree, the histological conditions. It is often difficult to read off from the X-ray film really small changes, and the figures we have been able to give may perhaps seem low. Yet even if one attaches pathological significance to disputable roentgenological changes, one arrives at a remarkably low frequency at early ages. However, the curve rises steeply, and at the ages of 50–60 we come up to 40 %, at 60–70 to 75 %. Thus an X-ray examination does not throw all the light on the anatomical conditions that is desirable as far as the radiating ruptures are concerned. They are, however, more distinctly observable with the aid of discography.

If the frequency of radiating ruptures is the same as the diagram shows, (we make some reservation in view of the fact that our material is not yet of the statistical scope that is desirable), then the frequency of the patient's suffering from lumbar pains at various ages should be the same in corresponding age groups if there were any connection between radiating ruptures and pain. The curve showing the frequency of pain in a certain clinical material (Friberg and Hirsch) has been transferred to the adjacent diagram. It is remarkable how the frequency of radiating ruptures in the two lower interspaces and the clinical low-back pain curve coincide as far as the age grouping is concerned. Had the frequency of rupture differed from the frequency of pain, one could certainly have ruled out the possibility of any connection between radiating ruptures and lumbago. The fact that the curves coincide does not of course afford any evidence of there being a connection between them, though it may substantiate the view we are presenting here.

Like our histological investigations, the curve also shows that radiating ruptures first arise in the lumbar discs situated higher up, when the fourth and fifth discs have played out their functional role as elastically mobile material. This may possibly be due to the fact that, when the lower discs no longer serve their purpose as elastic parts, the strain becomes greater on the discs lying above them and they then break. Radiating ruptures in discs number 1–3 therefore arise late, but they seldom reach the same extent as in the case of the two lower discs. This may perhaps be attributable to the fact that as age advances the water content in the intervertebral discs falls, so that their value as elastic material is greatly reduced–the entire back becomes stiff. This

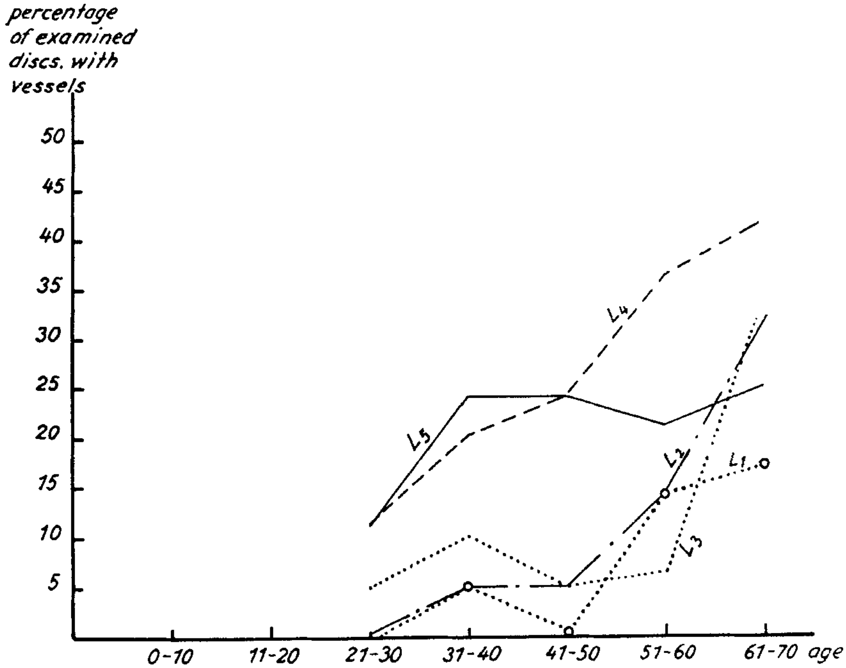


Fig. 26.
The frequency of vascular connective tissue in the posterior part of the lumbar annulus fibrosus in various disc-levels and ages.

is perhaps due to the fact that as we grow older our mechanical requirements decline–we are more chary about exerting ourselves.

The presence of vessels within the posterior portion of the annulus fibrosus in different discs and at different ages will be seen from fig. 26. Connective tissue with abundant vessels is far more commonly found in the two lowest intervertebral discs–owing to the frequency of radiating ruptures. In the more advanced ages, however, an adjustment takes place in the frequency in different discs, for the vessels never entirely disappear even if a rupture heals. The mere presence of vessels in the annulus fibrosus cannot explain the occurrence of pain. The functional condition of the disc is bound to have some effect. If the disc is stiff, the irritation becomes less pronounced in the area of the lesion.

DISCUSSION

Macroscopical and microscopical examinations of all the lumbar intervertebral discs in the material presented here show a very high frequency of radiating ruptures within the posterior part of the fourth and fifth discs. In cases where the annulus ruptures extend to the ligamentum longitudinale there is to be found in the cracked lamellar areas a highly vascular connective tissue emanating from the ligament. This connective tissue may be conceived of as a healing process. We have observed all transitional stages from recent undifferentiated connective tissue, reminiscent of granulation tissue, to mature, dense, connective tissue. This so-called "granulation tissue", however, seldom leads to true healing, i.e. to a scarred bridging-over of the annulus rupture. There frequently remains the fissure, partially covered by the highly vascular connective tissue, especially if the rupture is large and the nucleus pulposus is still more or less in good condition, so that the entire disc may still be presumed to possess a certain function, i.e. a certain degree of elasticity. The ingrowth of blood vessels in the annulus ruptures has previously been described by many authors. The opinion generally held is that it represents healing processes, being succeeded by cartilage and bone proliferation (Schmorl, Junghanns, Erdheim). Coventry, Ghormley and Kernohan first found vascularization of the annulus in a specimen from a woman aged 35. They said textually: "Several small thin-walled blood vessels were imbedded in the medial layers of the posterior portion of the annulus. They were grouped together and their lumen were filled with blood cells. This invasion of the fibro-cartilage of the annulus may be *an attempt on the part of the body to strengthen and nourish a structure which has become weakened and degenerated*".

As far back as 1929 Andrae mentions that in posterior prolapses capillaries may grow into them and, furthermore, in towards the annulus rupture and right into the nucleus pulposus. The presence of newly formed vessels, granulation tissue or fibrous connective tissue has been observed histologically in recent years by several authors in operatively removed disc prolapses (Eckert and Decker, Deucher, Love, Pais) in a fairly high percentage. Lindblom and Hultquist found a similar granulation tissue abounding in vessels and cells in 19 out of the 40 cases operated upon. They interpreted such phenomena as a sign of absorption of the prolapsed portion of the disc. As a result, not only the prolapses but also the symptoms of it may disappear. Those authors who in the course of animal experiments have studied the consequences of disc resections (Filippi, Tannman, Key and Ford, Olsson, Hansen) found a similar granulation tissue. Lindblom's and Hultquist's idea that it might be a question of absorption of prolapsed disc tissue may be refuted for the reason that this tissue already exists prior to the formation of the prolapses. As we see, the ingrowth of a highly vascular granulation tissue in a ruptured annulus has frequently been described and considered to be a healing process without having any clinical significance in regard to low back pain. Our material has shown that the vessel-connective-tissue reaction is particularly common at the ages of 30–50, i.e. when lumbago occurs most frequently. This has justified our posing the question: *Is it possible that this vascular connective tissue can induce pain?* Even if we were compelled to question the existence of nerve ends in the annulus under normal conditions–the question must be left open pending the result of more recent investigations–we consider ourselves right in assuming on the basis of the experience gained from general pathology that nerve fibres accompany the vascular connective tissue which, we have observed, penetrates into a ruptured annulus.

Busch found by the same method as Woollard nerves in the adventitia of the large blood vessels. According to Busch, similar nerves also frequently occur concurrently with smaller vessels, even capillaries, though in this case they are not found in the vessel walls. The nerve fibres and the nerve ends of the vessels are for the most part regarded as sympathetic. Leriche, however, writes (1939): "It is obvious, then, that there are two kinds of painful phenomena, those which exclusively concern a nerve of the cerebro-spinal type, and those which travel in the sympathetic or by the sympathetic, and reach the spinal cord only secondarily".

The appearance of a vascular connective tissue within the ruptured annulus tissue may explain why certain discs induce pain. *Granulation tissue in the intervertebral disc may be an important pathological basis for low back pain.*

SUMMARY

1. The lumbar spines from 105 fresh autopsy cases covering different ages have been examined roentgenologically. All the intervertebral discs have been cut through horizontally and examined macroscopically. In 65 cases all five lumbar discs have been systematically studied histologically. In addition, those of the remaining discs which macroscopically showed changes have been investigated histologically. One series of spines has been cut vertically in a sagittal and frontal direction and has been studied macroscopically and microscopically.

2. The annulus fibrosus or, better, lamellosus, since it consists of a lamellar system or fibro-cartilage, was already found distinctly developed in a 7-months-old foetus (25 cm.) and clearly distinguishable from the nucleus pulposus. The annulus assumes its final form and thickness through interstitial and appositional growth from the long ligaments, which are a continuation of the periosteum of the vertebrae and on the intervertebral discs represent a kind of perichondrium.

3. Ventrally and dorsally the annulus lamellae show distinct differences in regard to structure and course. Ventrally the ring is broader, the lamellae are more numerous and thicker. Its attachment to the anterior ligament is firmer than in the dorsal aspect. The ventral ligamunt is denser and has thicker fibres than the posterior. Towards the sides the annulus shows approximately the same structure as it does ventrally. The annulus is narrower in the dorsal aspect, and has fewer and thinner lamellae. The structure is not so distinctly marked. The attachment to the thinner posterior ligament is not so firm.

4. The annulus in the adult is entirely lacking in blood vessels. Before the epiphyseal nuclei of the vertebral bodies have become ossified, isolated vessels penetrate them from the perichondrium towards the marginal edge. In the adult there are vessels in the outer layer in the long ligament; these are fewer ventrally than dorsally. Dorsally, it may occur that one or two vessels extend to the annulus, but in that case they never penetrate into the annulus itself.

5. In our cases we have not found any nerve fibres in the annulus.

6. The annulus becomes metachromatic upon staining with toluidin blue, a fact that indicates that it retains a certain amount of mucopolysaccharides. It is, however, not as strongly metachromatic as the nucleus. The long ligaments do not stain violet and are not metachromatic.

7. The most common changes observable in the annulus are concentric cracks or cavities. They frequently occur as early as the fifteenth year and increase as age advances both in extension and in frequency. They must be regarded as physiological phenomena and can only be imagined to acquire pathological significance if the foci become very numerous and large, with the result that the fibrocartilaginous ring becomes weaker. Their occurrence may possibly be due to disturbances of the polysaccharides in the intercellular substance of the annulus fibrosus.

8. In a large number of cases, chiefly at the ages between 30 and 50, we have found radiating ruptures in the annulus. They are met with most frequently in the posterior part of the lower lumbar discs. If the rupture is complete and extends out towards the long ligament, there grows out from the latter a highly vascular connective tissue into the non-vascular annulus. If the rupture is small and not very extensive, a healing process, an overbridging of the annulus lesion, may set in. A fibrous scar is formed in the annulus. If, however, the rupture is more or less extensive and the disc still retains its elasticity, the ingrowth of connective tissue does not involve the formation of scars in the area in question. We have been able to follow all phases of develop-

ment between a very young undifferentiated, connective tissue and a firm abundantly fibrous connective-tissue scar, which, however, long retains its abundance of vessels.

9. The frequency of radiating ruptures is highest in the two lowest lumbar discs, in which they arise far earlier than in the intervertebral discs situated higher up. The occurrence of these ruptures coincides in time with those periods during which lumbago and sciatica show the highest clinical frequency and before X-ray photographs can throw any light on the condition of the intervertebral disc.

10. For the purposes of discussion the authors present the idea that the appearance of a highly vascular granulation tissue within the intervertebral disc may constitute a new pathological basis for low back pain.

RÉSUMÉ

1. On a examiné radioscopiquement la colonne lombaire après autopsies de fraîche date chez 105 individus d'âges différents. Tous les disques intervertébraux ont été coupés horizontalement et étudiés macroscopiquement. Dans 65 colonnes tous les cinq disques lombaires ont été systématiquement étudiés au point de vue histologique. De plus, ceux des autres disques qui macroscopiquement montraient des modifications ont été étudiés histologiquement. Une série de rachis ont été coupés verticalement dans le sens sagittal et frontal et étudiés macroscopiquement et microscopiquement.

2. Chez un foetus de 7 mois (25 cm.) on a trouvé l'anneau fibreux, ou mieux dit lamelleux, puisqu'il consiste en un système de lamelles de fibrocartilages, déjà nettement développé et pouvant être clairement distingué du nucleus pulpeux. L'anneau prend sa forme et son épaisseur définitives par une croissance interstitielle et appositionelle provenant des longs ligaments, qui sont une continuation du périoste des vertèbres et représentent sur les disques intervertébraux une sorte de périchondre.

3. Les lamelles de l'anneau présentent des différences marquées dans la structure et l'épaisseur suivant qu'il s'agit du côté antérieur ou postérieur. Du côté ventral, l'anneau est plus large, les lamelles sont plus nombreuses et plus épaisses. Son lien avec le ligament antérieur est plus ferme que du côté postérieur. Le ligament ventral est plus dense et composé de fibres plus grosses que celui de derrière. Sur les côtés, l'anneau montre à peu près la même construction que du côté ventral. L'anneau est plus étroit du côté dorsal et ses lamelles sont moins nombreuses et plus minces. Sa structure n'est pas si nettement

marquée. Le lien avec le ligament de derrière plus mince, n'est pas si ferme.

4. Chez les adultes, l'anneau est entièrement dépourvu de vaisseaux sanguins. Avant que les noyaux épiphysiaires ne se soient osséifiés, des vaisseaux isolés pénètrent du périchondre vers le rebord. On rencontre chez les adultes des vaisseaux dans les couches extérieures des longs ligaments, moins du côté du ventre que du côté du dos. Du côté du dos, il peut se produire que quelques vaisseaux arrivent jusqu'à l'anneau, mais ils ne pénètrent jamais dans l'anneau lui-même.

5. Dans les cas que nous avons examinés, nous n'avons pas trouvé de filaments nerveaux dans l'anneau.

6. L'anneau est métachromatique à la coloration au bleu de toluidine, ce qui semble indiquer qu'il a une certaine teneur de mucopolysaccharides. Cependant, il n'est pas aussi fortement métachromatique que le nucleus pulpeux. Les longs ligaments ne prennent pas la couleur violette; ils ne sont pas métachromatiques.

7. Les modifications les plus habituelles que l'on peut rencontrer dans l'anneau sont des fissures concentriques ou des formations de cavilés. Elles se manifestent souvent déjà chez des individus de 15 ans et augmentent avec les années, tant en extension qu'en fréquence. Elles doivent être considérées comme des phénomènes physiologiques et ne doivent avoir d'importance pathologique que si les foyers deviennent très nombreux et étendus, de sorte qu'ils conduisent à un affaiblissement de l'anneau fibrocartilagineuse. Il est possible que leur présence soit due à des perturbations polysaccharides de la substance intercellulaire de l'anneau fibreux.

8. Dans un grand nombre de cas, principalement entre 30–50 ans, nous avons rencontré des ruptures radiaires de l'anneau. On les trouve le plus fréquemment dans le champ arrière des disques lombaires inférieurs. Si la rupture est totale et va jusqu'au long ligament, il croît de ce dernier un tissu conjonctif riche en vaisseaux, qui pénètre dans l'anneau dépourvu de vaisseaux. Si la rupture est petite et peu étendue, une guérison – à savoir un recouvrement de la lésion de l'anneau – peut se produire. Il se forme une cicatrice fibreuse dans l'anneau. Cependant, si la rupture est assez étendue et que le disque ait par ailleurs gardé son élasticité, la croissance de tissu conjonctif n'entraîne pas de formation de cicatrice dans le champ en question. Nous avons pu voir toutes les phases de développement depuis un tissu conjonctif très jeune, non différencié, ressemblant à un tissu de granulation jusqu' à une cicatrice de tissu conjonctif riche en fibres, ferce, qui garde cependant longtemps sa richesse en vaisseaux.

9. Les ruptures radiaires sont surtout fréquentes dans les deux

disques lombaires inférieurs ou elles se produisent sensiblement plus tôt que ce n'est le cas dans les disques intervertébraux situées plus haut. La manifestation de ces ruptures coincide quant au temps avec les périodes où le lumbago et la sciatique montrent la plus grande fréquence clinique, et avant que les rayons X ne donnent de renseignements au sujet de l'état du disque intervertébral.

10. Les auteurs présentent à la discussion l'hypothèse qu'un tissu de granulation riche en vaisseaux du disque intervertébral pourrait peut-être constituter le fondement pathologique du lumbago.

RESUMEN

1. Se ha examinado radioscópicamente la columna lumbar, de autopsias recientes, de 105 individuos de diferentes edades. Todos los discos intervertebrales han sido cortados horizontalmente y estudiados macroscópicamente. En 65 columnas, los cinco discos lumbares han sido sistemáticamente estudiados desde el punto de vista histológico. Además en las otras columnas los discos que macroscópicamente mostraban variaciones han sido estudiados histológicamente. Una serie de columnas han sido cortadas verticalmente en sentido sagital y frontal y estudiadas macro y microscópicamente.

2. Ya en un feto de 7 meses (25 cm) se ha encontrado el anillo fibroso, o mejor dicho laminoso, puesto que consiste en un sistema de láminas de fibrocartilago, claramente desarrollado y que puede ser fácilmente distinguido del núcleo pulposo. El anillo adquiere su forma y su espesor definitivos mediante un crecimiento intersticial y aposicional procedente de los ligamentos longitudinales que son una continuación del periostio de las vértebras y representan en los discos intervertebrales una especie de pericondrio.

3. En el lado ventral y en el dorsal, las láminas del anillo presentan diferencias manifiestas en la estructura y en el espesor. Del lado ventral, el anillo es más ancho, y las láminas son más numerosas y más gruesas. Su conexión con el ligamento longitudinal anterior es más firme que del lado posterior. El ligamento anterior es más denso y está compuesto de fibras más gruesas que el posterior. A los lados, el anillo muestra aproximadamente la misma estructura que en el lado ventral. El anillo es más delgado del lado posterior y sus láminas son menos numerosas y más finas. La estructura no está tan claramente marcada. La conexion con el ligamento posterior, más delgado, no es tan firme.

4. En los adultos, el anillo está totalmente desprovisto de vasos sanguíneos. Antes de que los nucleos epifisarios se hayan osificado, los vasos aislados penetran del pericondrio hacia el borde. En los

adultos, se encuentran menos vasos en las capas exteriores de los ligamentos longitudinales anteriores que en los posteriores. Del lado dorsal puede ocurrir que algunos vasos lleguen hasta el anillo, pero no penetran jamás en el mismo.

5. En los casos que hemos examinado, no hemos encontrado filamentos nerviosos en el anillo.

6. El anillo es metacromático a la coloración del azul de toluidina, lo que parece indicar que tiene cierto tenor de mucopolisacáridos. Sin embargo, no es tan fuertemente metacromático como el núcleo pulposo. Los ligamentos longitudinales no adquieren el color violeta; no son metacromáticos.

7. Los cambios más corrientes que se pueden encontrar en el anillo son fisuras concéntricas o formaciones de cavidades. Se manifiestan a menudo ya en los individuos de 15 años y aumentan con los años, tanto en extensión como en frecuencia. Deben ser consideradas como fenómenos fisiológicos y parecen no tener importancia patológica más que cuando los focos son muy numerosos y están muy extendidos, de manera que conducen a la debilitación del anillo fibrocartilaginoso. Es posible que su presencia sea debida a perturbaciones de los polisacáridos de la substancia intercelular del anillo fibroso.

8. En numerosos casos, principalmente entre los 30 y los 50 años, hemos hallado rupturas radiales del anillo. Se las encuentra más frecuentemente en la región posterior de los discos lumbares inferiores. Si la ruptura es total y llega hasta el ligamento longitudinal, crece de este último un tejido conjunctivo muy rico en vasos, que penetra en el anillo desprovisto de ellos. Si la ruptura es pequeña y poco extendida, puede producirse una curación, es decir, que se vuelve a cubrir la lesión del anillo, formándose en este último una cicatriz fibrosa. Sin embargo, si la ruptura es bastante extensa y el disco conserva además su elasticidad, el crecimiento del tejido conjuntivo no lleva consigo la formación de cicatriz en el campo en cuestión. Hemos podido ver todas las fases del desarrollo desde un tejido conjuntivo muy joven, no diferenciado y parecido a un tejido de granulación, hasta una cicatriz formada por tejido conjuntivo rico en fibras, denso, que guarda largo tiempo, sin embargo, su riqueza en vasos.

9. La frecuencia de las rupturas radiales es mayor en los dos discos lumbares inferiores y se producen allí mucho más pronto que en los discos intervertebrales situados más arriba. La aparición de estas rupturas coincide en cuanto a las edades con los períodos en que el lumbago y la ciática acusan la mayor frecuencia clínica, y antes de que los rayos X den una indicación sobre el estado del disco intervertebral.

10. Los autores emiten la hipótesis de que un tejido de granulación

altamente vascularizado en el disco intervertebral podría constituir un substractum anatomo-patológico del lumbago.

ZUSAMMENFASSUNG

1. Es wurden 105 Lendenwirbelsäulen von frischen Sektionsfällen, die verschiedene Alter umfassten, röntgenologisch untersucht. Sämtliche Intervertebralscheiben sind horizontal durchschnitten und makroskopisch- und in 65 Wirbelsäulen alle fünf Lumbalbandscheiben systematisch histologisch untersucht worden.

Ausserdem sind von den übrigen Bandscheiben diejenigen, die makroskopisch Veränderungen zeigten, histologisch untersucht worden. Eine Reihe von Wirbelsäulen ist vertikal, in sagittaler und frontaler Richtung, geschnitten und makro- und mikroskopisch untersucht worden.

2. Der Annulus fibrosus oder besser lamellosus, da er aus einem Lamellensystem aus Faserknorpel besteht, zeigte sich bereits bei einem 7 Monate alten Foetus (25 cm) deutlich entwickelt und deutlich vom Nucleus pulposus unterscheidbar. Der Annulus erreicht seine schliessliche Form und Dicke durch interstitielles und appositionelles Wachstum von seiten der langen Ligamente, die eine Fortsetzung des Periosts der Wirbelkörper sind und auf den Intervertebralscheiben eine Art Perichondrium darstellen.

3. Ventral und dorsal zeigen die Annuluslamellen deutliche Unterschiede hinsichtlich Struktur und Verlauf. Ventral ist der Annulus breiter, die Lamellen sind zahlreicher und dicker.

Seine Verbindung mit dem vorderen Ligament ist fester als mit dem dorsalen. Das ventrale Ligament ist dicker und grobfaseriger als das hintere. Seitlich zeigt der Annulus ungefähr denselben Aufbau wie ventral. Der Annulus ist dorsal schmäler, er hat weniger und dünnere Lamellen und die Struktur ist nicht so deutlich markiert. Die Verbindung mit dem dünneren hinteren Ligament ist nicht so fest.

4. Der Annulus ist, wenn man von einzelnen Gefässen absieht, die während der Verknöcherung des Epiphysenkernes der Randleiste vom Perichondrium aus eindringen, zeitlebens vollkommen *gefässfrei*. Gefässe gibt es nur in den äusseren Schichten der Ligamente, weniger vorne als hinten, hier manchmal bis zum Annulus reichend, aber nie in ihn eindringend.

5. Wir haben in unseren Fällen keine Nervenfasern im Annulus gefunden.

6. Der Annulus ist metachromatisch bei Färbung mit Toluidinblau, was dafür spricht, dass er einen gewissen Gehalt an Mucopolysaccha-

riden besitzt. Er ist jedoch nicht so stark metachromatisch wie der Nucleus. Die langen Ligamente färben sich nicht violett sie sind nicht metachromatisch.

7. Die am häufigsten gefundene Veränderung des Annulus ist die sogenannte „schleimige Degeneration", die schon beim Jugendlichen, gewöhnlich beim 15 jährigen, beginnt und mit zunehmendem Alter an Ausdehnung und Häufigkeit zunimmt und zu konzentrischen Spalten- oder zur Höhlenbildung führen kann. Sie kann als physiologische Abnützungserscheinung betrachtet werden, die nur pathologische Bedeutung erreicht, wenn die Herde sehr zahlreich und gross sind, sodass sie zu einer Schwächung des Bandapparates führen. Es ist möglich, dass ihr Vorkommen durch Polysaccharidstörungen in der Intercellularsubstanz des Annulus fibrosus bedingt ist.

8. In einer grossen Anzahl von Fällen, hauptsächlich im Alter zwischen 30–50 haben wir radiäre Rupturen im Annulus gefunden. Sie werden am häufigsten im hinteren Bereich der unteren Lumbalbandscheiben angetroffen. Wenn die Ruptur durchgehend ist und das Längsband erreicht, wächst von diesem ein gefässreiches Bindegewebe in den gefässfreien Annulus hinein. Wenn die Ruptur gering und wenig ausgebreitet ist, kann eine Heilung, eine Überbrückung, des Annulusrisses zustande kommen.

Es bildet sich eine fibröse Narbe im Annulus. Ist jedoch die Ruptur sehr ausgedehnt und hat die Bandscheibe im übrigen ihre Elastizität behalten, so führt das Einwachsen des Bindegewebes keine Narbenumwandlung in diesem Gebiete herbei.

Wir haben alle Entwicklungsphasen von einem sehr jungen undifferenzierten, granulationsartigen Bindegewebe bis zu einer derben, faserreichen Bindegewebenarbe, die jedoch lange ihren Gefässreichtum beibehält, sehen können.

9. Die Frequenz der radiären Rupturen ist am grössten in den beiden untersten Lumbalbandscheiben und tritt hier erheblich früher auf als in den höheren Intervertebralscheiben. Das Auftreten dieser Rupturen fällt zeitlich mit den Perioden zusammen, während denen Lumbago und Ischias die grösste klinische Frequenz aufweisen und noch bevor im Röntgenbilde der Zustand der Intervertebralscheiben erkennbar ist.

10. Die Verfasser glauben, dass ein sehr gefässreiches Granulationsgewebe eine wichtige pathologisch-anatomische Grundlage der Rückenschmerzen darstellen könnte.

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