FROM THE ORTHOPAEDIC DEPARTMENT OF KAROLINSKA INSTITUTET, STOCKHOLM. CHIEF: PROFESSOR STEN FRIBERG.

STUDIES ON THE MECHANISM OF LOW BACK PAIN

By

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THE STRUCTURE OF THE DISC

The intervertebral discs are made up of three types of tissue. Plates, consisting of hyaline cartilage, separate them from the vertebral bodies. A solid elastic ring, annulus fibrosus, forms the main mass of the disc and encloses a somewhat eccentrically situated plastic tissue, nucleus pulposus, a watery gel composed of a dense collagen structure permeated with polysaccharides, probably consisting of chondroitin sulphuric acid.

The disc is covered dorsally and ventrally by ligamentum longitudinale post. and ant. respectively. In the adult the intervertebral disc lacks vessels. There is an abundance of nerve ends in lig. long. post, whereas the disc itself is without sensitive end organ, though these possibly occur in the posterior external parts of annulus fibrosus (Hovelaque, Roofe, Wiberg).

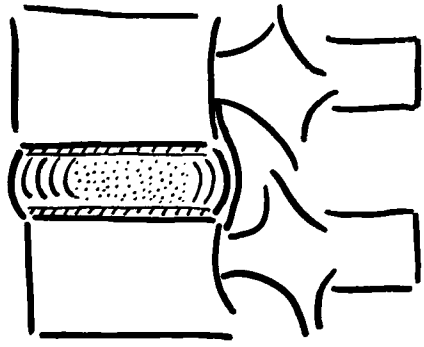

Fig. 1.
Drawing of an intervertebral interspace.

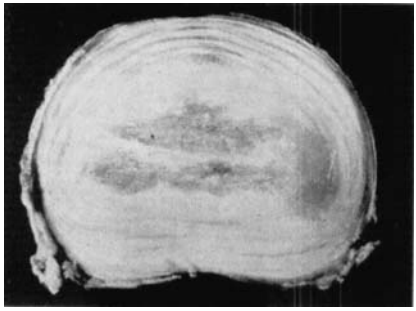

Fig. 2.
Cross section of a normal disc.

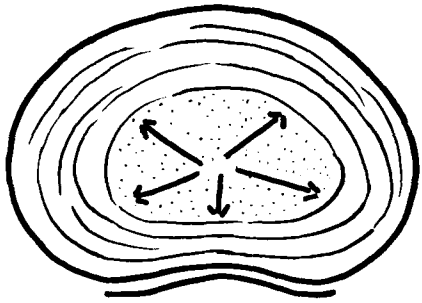

Fig. 3.
Drawing of the pressure mechanism.

MECHANICAL VIEWS ON THE DISC

Regarded mechanically, the intervertebral disc is an elastic interposition between solid parts, the vertebral bodies, and acts with its three tissue elements as a functional unit (Joplin).

The intervertebral joints and ligaments have no supporting function; they limit the extent of movement of the elastic pillar, the spine, as regards both direction and magnitude. The extensive contact of the intervertebral disc with the adjoining osseous tissue compared with that of the intervertebral joints, the firmness with which the disc is bound to the vertebral bodies and the sluggishness of the disc in respect of movements thereof, make the intervertebral disc one of the first factors to be considered when seeking tissue elements which functionally have to take up the strains that must necessarily arise in conjunction with mechanical stresses.

If the intervertebral disc is subjected to load from any direction, the result is a change in the shape of the disc. The disc assumes a state of equilibrium, and if the forces that are acting lie within the normal physiological limits, that part of the deformation which is apparent to the eye may be quite insignificant. Equilibrium will have occurred because the nucleus pulposus will have moved out in various directions and distributed the pressure around the entire annulus fibrosus. A distribution of tension in small doses takes place in the elastic ring. The efforts of the nucleus pulposus to extrude are prevented by the annulus fibrosus. The mechanical action exerted upon the nerve-carrying posterior ligament is small.

MECHANICAL EXPERIMENTS

The mechanical reasoning advanced here is based on direct experimental measurements. In a press such as that shown in fig. 4 and 5

the whole lumbar spine including the sacrum can be subjected to load. The specimens studied were obtained from fresh autopsy cases. It was possible to determine the forces applied in the apparatus as regards both direction and magnitude. The experimental devices are such that the back can be moved in all directions and even rotated by means of

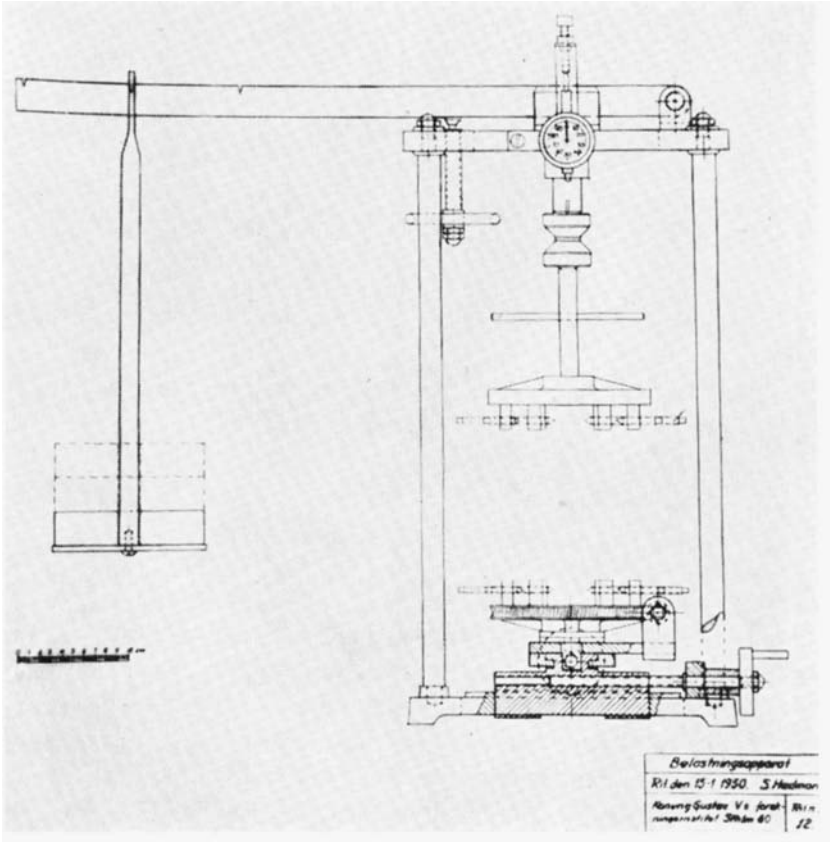

Fig. 4.
Working drawing of the press.

a gear system operated from the base-plate of the compressor. By means of the lever arm, effective vertical pressures up to 25 kg were applied. The moment at which the back reached equilibrium was determined by a dial indicator. When the indicator showed that no further movement could be recorded in the system upon which the lever was acting, it was time to study more closely what kind of reaction had taken place in the intervertebral discs.

On palpation of the annulus fibrosus of the lumbar discs it was possible to feel how the discs hardened while the loading test was

proceeding. In order to enable a more exact estimation of changes of pressure in the discs to be made, allowing comparisons to be drawn between different discs and providing an opportunity of evaluating mechanically and functionally the changes in the intervertebral discs, a pressure meter was designed (figs. 6 and 7). This is based on the

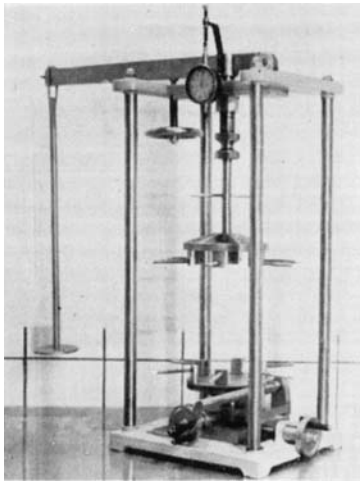

Fig. 5.
The press when completed.

following principles. A pelot is thrust in against a disc's extreme edge, applying a force that can be varied. The pressure, which is delivered manually, is transmitted via a spring along which a graduated scale gives the pressure in kg. In the experiments described here the pressure was maintained at between 1 and 3 kg. A relative measure of a given disc's firmness at the moment it assumed equilibrium for a given load is obtained if the impression made by the pelot is recovered. The measuring instrument was so designed that the distance the pelot could penetrate the disc was read off on a dial indicator.

Tests with the above instruments were made on discs from fresh autopsy material. The specimens taken were selected so that one group could represent a normal category in respect to the morphology of the intervertebral disc. The discs were taken from individuals who were about 20 years of age. All the backs were X-rayed before the tests started, and after the measurements had been taken, the discs were cut across so that the sections could be inspected. Another group comprised loins in which the X-ray showed disc degeneration, diagnosed from narrowed interspace, sclerosis and more or less pronounced osteophytes, or else the X-ray was normal while the gross section was typical of

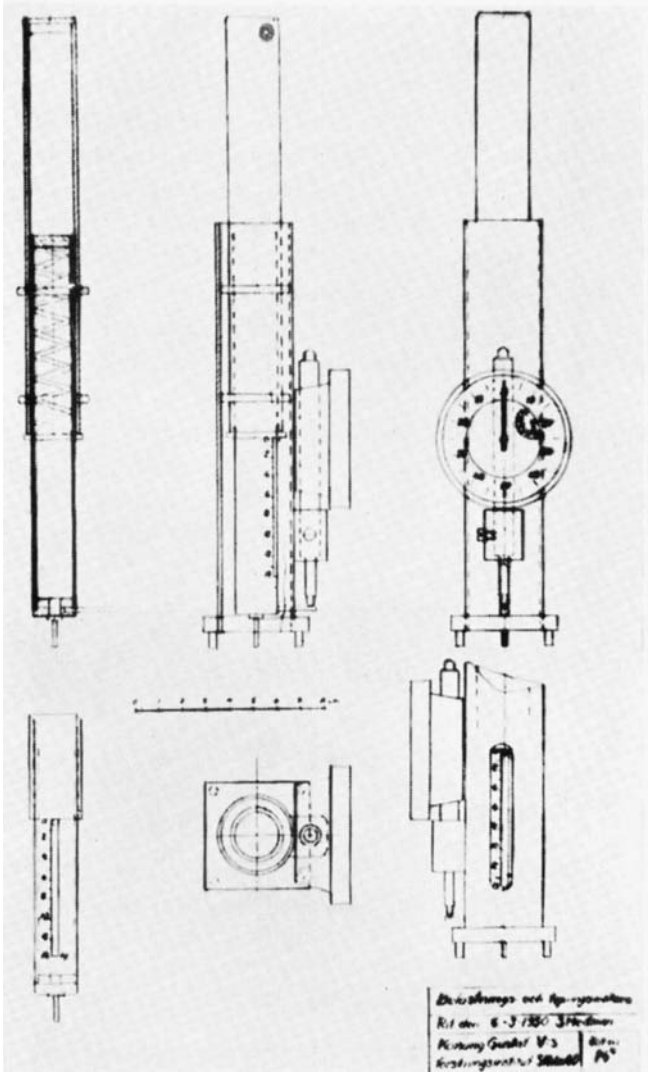

Fig. 6.
Working drawing of pressure meter.

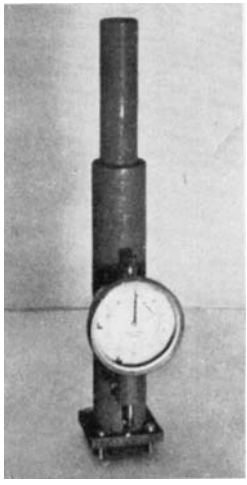

Fig. 7.
The pressure meter when completed.

a disc degeneration with necrosis in both annulus and nucleus. This latter group came chiefly from 40-year-olds.

In the "healthy" group the penetrability of the pelot under the same degree of compression was identical. In the disc degeneration group conditions varied considerably, but it differed from the former to the extent that the pelot could as a rule penetrate more easily. In different areas of the same disc, however, the pressure varied. *Disturbances in the structure of an intervertebral disc produce variable pressure conditions and thus change the mechanical value of a given intervertebral disc. This leads to deformations and tension disturbances, which may be large in some sections and which, in particular, can arise very rapidly.*

In earlier investigations made by the author in collaboration with Friberg it was found that ruptures in the dorsal area of the lower lumbar discs were very common in cases of disc degeneration. The consequence of rupture in the annulus fibrosus is the diminishing of

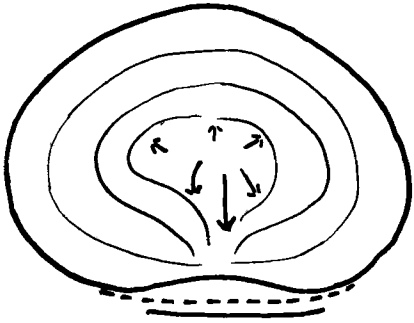

Fig. 8.
Sketch of annulus rupture which arose medially posteriorly.

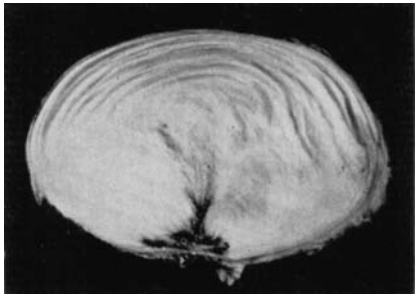

Fig. 9.
Section through disc with posterior rupture.

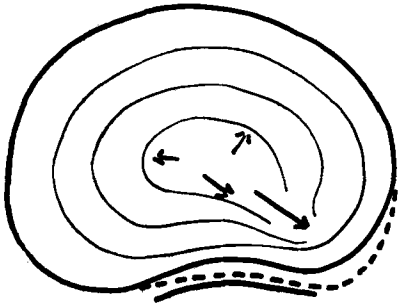

Fig. 10.
Sketch of annulus rupture which arose laterally posteriorly.

Fig. 11.
Section through disc with lateral rupture.

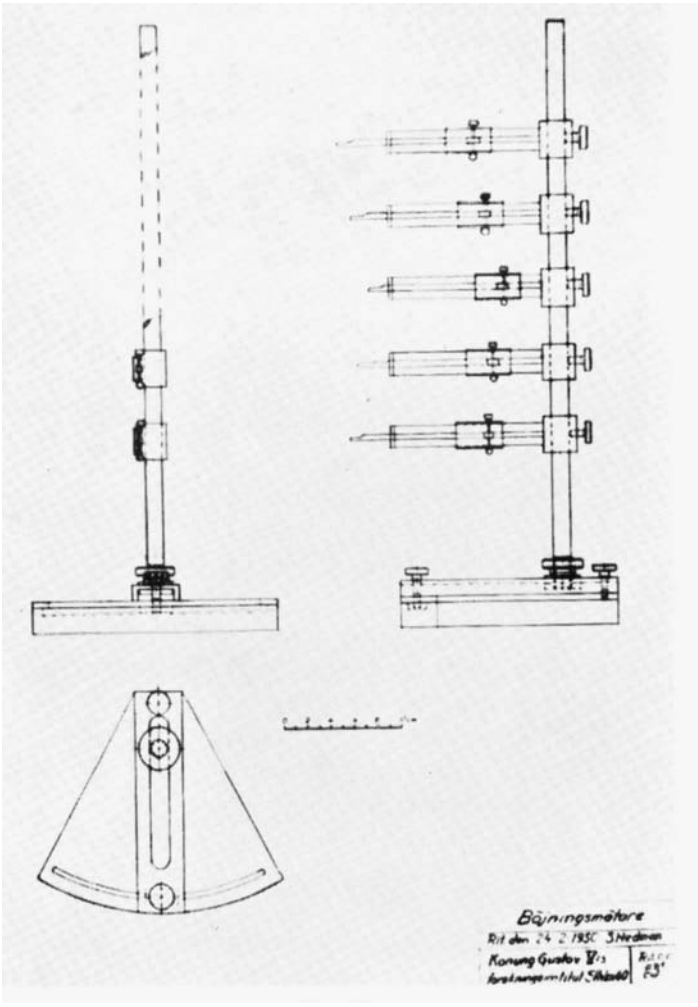

Fig. 12.
Working drawing of sliding calipers.

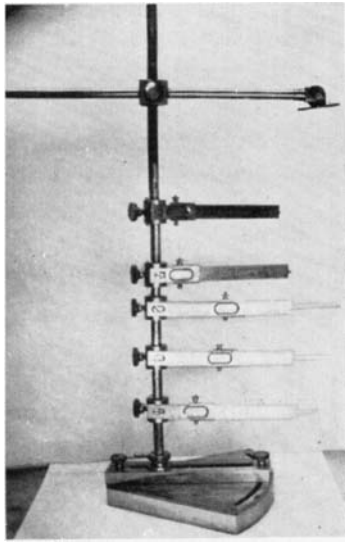

Fig. 13.
The sliding calipers completed.

its resistance to mechanical strain. A deformation posteriorly will be the result of a load (see figs. 8-11).

Knutsson has demonstrated from clinical material that abnormal mobility may arise between lumbar vertebrae. He interpreted this as a sign of disc degeneration. The author in collaboration with Friberg has found that such abnormal mobility, the anatomical conditions of the vertebrae being otherwise normal, is governed by degenerative changes in the intervertebral discs, i.e. ruptures in the dorsal area of the annulus fibrosus. According to the results obtained from pressure measurements, these changes lead to such variations in the tension conditions in the discs, i.e. in the interdiscal pressures, that the stability between the vertebrae is disturbed.

When the back is bent in different directions each individual vertebra performs a rotary movement. The size and direction of this twisting movement are determined in no small measure by the functional condition of the disc beneath. This can be observed directly by means of ordinary sliding calipers fitted onto a stand (figs. 12 and 13). The experiments on which the above observations are based were carried out in the following manner. A complete lumbar spine was fixed in a vice. In each vertebra two metal pins were fixed as points of measurement. Close to the vertebrae a number of sliding calipers were fixed, two for each vertebrae, each in line with a metal pin. The back was then bent in a given direction and, when equilibrium was achieved, the distance from the fixed stand to the metal pins was measured. From a series of measurements following up each fresh extension of flexion the degree of rotary movement could be ascertained.

If the structure of a given intervertebral disc is modified, there arise changes in stress, and the path of movement of the vertebra above is altered. In this way parallel displacements may occur—indeed in such a degree that they are even visible on an X-ray plate. This is what Knutsson called instability. But, in addition, a (increased) rotation may occur, and the result of this will be, besides a certain parallel displacement, an increased angle between the vertebrae. This, indeed, is something that can very often be found in X-ray photographs of clinical material. The alternatives that arise in such a situation are shown in figs. 14-16. The proximal vertebra can be displaced parallel posteriorly and then rotate, or can be displaced parallel anteriorly and rotate. Both these forms were observed by Knutsson. What will take place must depend upon how the forces will act or what the structural changes will be in a given case. Disturbances in the motility of the vertebrae lead to deformations in the interverte-

bral discs, stresses in lig. longitudinalia and strains in the intervertebral joints.

It is now a recognized fact that sciatica is often due to a local deformation in an intervertebral disc. Whether lumbago can be traced back to a disturbance of function in an intervertebral disc is still a question that many are prepared to consider, even though they may not accept it entirely. If abnormal pressure conditions in the discs could provide an explanation for pain arising in the back it should be possible to demonstrate this by experimental means. The author

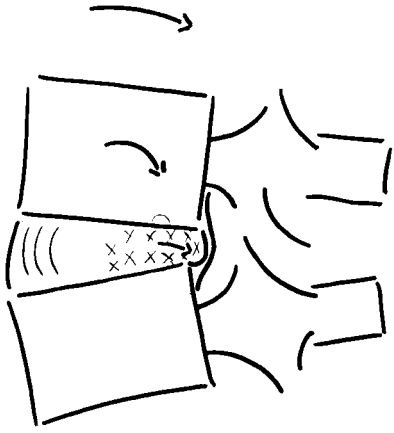

Fig. 14.
Abnormal motion between vertebras when the disc is degenerated. Bending backwards.

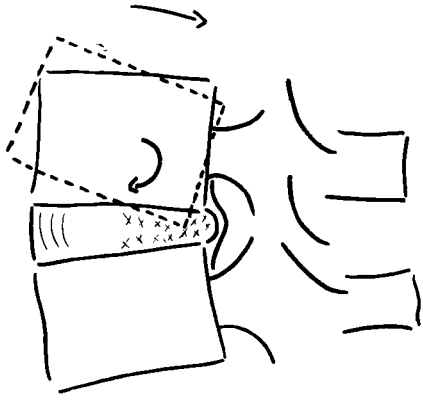

Fig. 15.
Abnormal motion between vertebras when the disc is degenerated. Bending backwards.

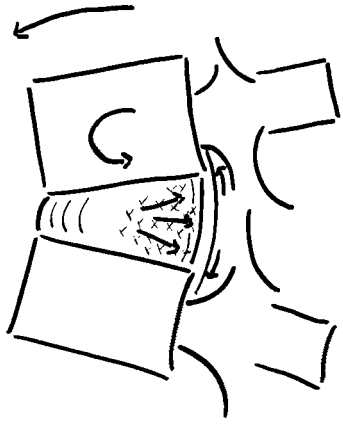

Fig. 16.
Bending forwards.

reasoned in this manner when in 1948 he published his first experiences with *disc puncture*. A fine needle was inserted transdurally in two or three lumbar discs under X-ray control, and normal saline solution was injected under pressure. With a healthy disc it was only possible to introduce some tenths of a cubic centimetre, even when the pressure was considerably raised. Nothing happened. In a degenerated disc, up to 1 or 2 cc. could be injected. So long as the pressure was low the patient noticed nothing, but if the pressure was raised during the

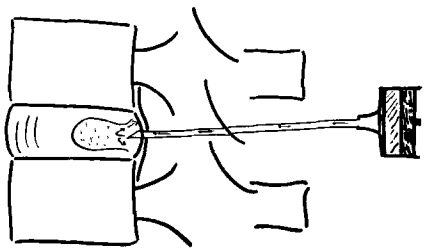

Fig. 17.
Disc-puncture.

injection the patient in some cases suffered violent pain of a type which he could clearly identify as the pain he was accustomed to during an attack of lumbago. When the pressure in the syringe was allowed to fall the pain disappeared. The experiment could be repeated any number of times and always with the same result. It was the pressure alone that determined the violence of the pain that was caused. If the saline injections were preceded by the injection of 0.5-1 cc. 1 % novocain, no pain was caused. The observations made in these experiments were interpreted by the author as indicating that intradiscal pressure above a certain level causes an attack of lumbago, probably via lig. long. post. Anaesthetizing the posterior region of the disc will lead to a blocking of the nerve ends of lig. long. post., and pain will no longer be caused. Lig. long. post. might be considered a pressure-recording body which, upon irritation over a certain level, gives rise to lumbago.

The investigations made up till now into clinical material have shown that relatively often the lumbago may be simultaneously produced in a patient from more than one disc. It may even occur that three discs produce pains in the lumbar spine, all of which the patient may believe to be the source of his existing lumbago. Considering the great frequency of the degenerative changes observed during the anatomical examinations this would seem to be reasonable. Furthermore,

no correlation exists between the disc alterations observed on X-ray plates and the interspaces that produce the pains. This is in complete conformity with the observations made previously by Friberg and the author, on the basis of their anatomical studies. A negative X-ray plate does not exclude the possibility of considerable changes in the intervertebral discs.

The practical consequence of the views expressed above must be accepted when a decision has to be made on the advisability of surgical intervention in a specific case. If an osteosynthesis is to be carried out, the X-ray plate does not afford any guidance. *The fact that a disc is shown by the X-ray image to be low, need not by any means imply that it is the cause of the pain.* As the mechanical and anatomical examinations have shown, it may have completely lost its function, and may simply indicate a fibrous anchylosis. The purpose of the osteosynthesis is to eliminate that function of the discs from which the pain is produced. The investigations made in this matter have demonstrated the importance of ascertaining the real origin of this pain. Regarding the technique I would refer my readers to the articles published in this number of Acta Orthopedica by Lindblom and Perey.

DISCUSSION

The investigations made by Friberg and the author have shown the great frequency of degenerative changes in the lumbar intervertebral discs. They appear so frequently even at early ages that they must be considered more or less physiological. As early as the age of 20 manifest structural transmutations may be observed in the nucleus pulposus in a stage which can be characterized as an initial necrosis of the tissue. In none of the 500 histological specimens examined by the author has any healing process been observed in the histological sense of the term. The decomposition of the nucleus is a continual process. The cause of this process has not yet been elucidated. Studies of the biochemistry and the ultra structure of the nucleus at different ages are being made by the author in collaboration with Sylvén, Snellman and Paulson. These researches are still in the preliminary stage. As to the results, I would refer readers to papers now in the press (see *Literature*). The transmutations in the nucleus pulposus do not appear, in regard to their frequency, to be confined to certain interspaces, but are found to occur in all the lumbar discs. The histological examinations have convinced the author that the annulus fibrosus suffers injury later than the nucleus and that in this respect there exists a certain relation between the degree of decomposition of the

nucleus and that of the annulus. Not until the nucleus exhibits advanced changes do ruptures begin to occur in the annulus. These observations led the author to wonder whether the nucleus does not play an essential part in the entire functioning of the disc. So long as the nucleus consists of a plastic substance with a high percentage of water it contributes towards an equal distribution of pressure over the whole area of the intervertebral disc. If it loses part of this faculty such mechanical stresses and strains arise in the surrounding annulus that the latter is no longer capable of meeting even physiological demands made on it—, and there is a rupture. In that event conditions arise which may cause such changes in the form of the disc as may produce a mechanical irritation in the long ligaments and the sensitive end organs that are situated there. Now, there could easily arise such variations in the pressure that in certain cases pain would be produced, even as a result of strains which need not at all be very great, which indeed may even lie within physiological limits.

An attempt has been made in this paper to study more closely the effect of the variations of pressure in the intervertebral discs. A description has been given of the measuring instruments which have made this study possible. The experiments carried out have shown that more or less extensive ruptures in the annulus fibrosus produce such variations in the different sections of one and the same intervertebral disc, even for small mechanical strains, that considerable disturbances are caused both in the relative position of the surrounding vertebrae and in the form assumed by a given disc when equilibrium is reached after a certain load.

The author has also been able to show by puncturing the discs in living material, that changes in the intradiscal pressures, in cases of rupture of the annulus, cause sensations of pain of the same kind as those felt by lumbago patients.

There is much evidence in favour of the view that lumbago is to be regarded as a functional disturbance in one or several discs, primarily caused by such a change in the biological composition of the nucleus pulposus that its plasticity is modified, resulting in a rupture of the annulus fibrosus. The whole disc no longer functions normally. Even slight strains may produce pain.

SUMMARY

The author gives an account of new technical devices which have enabled him to study the function of the lumbar intervertebral discs. His investigations support the opinion that disturbances in the varia-

tions of pressure that arise in lumbar discs are frequent in ruptures of the annulus. As a result disturbances are caused both in regard to the relative position of the surrounding vertebrae and in regard to the deformation by which any particular intervertebral disc responds to a given mechanical strain. The variability thus occasioned even by a physiological use of the back may cause such irritation of the sensitive end organs of the long ligaments as to produce lumbar pain.

RESUME

L'auteur décrit de nouveaux procédés techniques qui lui ont permis d'étudier la fonction des disques lombaires intervertébraux. Ses recherches corroborent l'opinion selon laquelle les perturbations des variations de pression qui se produisent dans les disques lombaires sont fréquentes dans le cas de rupture de l'anulus. Il en résult des perturbations tant dans la position relative des vertèbres avoisinantes qu'en ce qui concerne la déformation par laquelle chaque disque intervertébral répond à un effort mécanique donné. Cette variabilité, occasionnée même par l'usage physiologique du dos, peut causer une telle irritation des sensibles organes terminaux des longs ligaments que cela provoque une douleur lombaire.

ZUSAMMENFASSUNG

Der Verfasser gibt einen Bericht über neue technische Anordnungen mittels deren er die Wirkungsweise der lumbaren intervertebralen Scheiben studieren konnte. Seine Untersuchungen stützen die Auffassung, dass Störungen der Druckänderungen, die in den lumbalen Scheiben auftreten, häufig bei Brüchen des annulus sind. Störungen werden daher sowohl bezüglich der relativen Lage der umgebenden vertebrae hervorgerufen wie bezüglich der Deformation, durch die jede einzelne intervertebrale Scheibe einer bestimmten mechanischen Beanspruchung entspricht. Die dadurch verursachte Veränderlichkeit auch durch physiologische Anwendung des Gesässes kann solche Irritation der sensitiven Endorgane der langen Ligamente hervorrufen, dass lumbare Schmerzen entstehen.

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