EXPERIMENTAL INVESTIGATIONS INTO THE PHYSICAL PROPERTIES OF THE INTERVERTEBRAL DISC

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An investigation of the elastic properties of the intervertebral disc was undertaken in order to ascertain their contribution to the function of the vertebral column. As a result certain data have been accumulated which may have an important bearing on the problems arising from degenerative and traumatic lesions of intervertebral discs.

EXPERIMENTAL PROCEDURE

A series of experiments was carried out using an Olsen compression-testing machine, which records the force necessary to compress the object between the plates of the machine (the load) and the loss of height of the object (the deflection). The technique was as follows: an intervertebral disc was removed at autopsy; a thin slice of bone at each end of the disc was included. The specimen was kept in Ringer's solution before and during the tests. It was compressed by successive increments of 50 lb. Material was obtained from fifty-one cadavers and one to five discs were tested from each subject.

The experiments were divided into seven groups:
1) The loading was continued until the disc began to lose height.
2) The discs were loaded up to 500 lb. and then unloaded to zero.
3) Two successive tests were made on one disc with a time interval between the tests.
4) After two successive tests an incision was made with a scalpel into the centre of the disc through the postero-lateral part of the annulus fibrosus, and then a third test was carried out.
5) In this group there were two tests, then an incision, and then two more tests. The disc was then allowed to remain in Ringer's solution for about twenty hours.
6) The preceding tests were carried out on sections of the spine containing four lumbar vertebral bodies and three complete discs.
7) A series of discs were placed under a constant load of 50 lb. for periods up to forty-eight hours. Continuous measurements of the deflections during this period were recorded.

In order to appreciate the results of these experiments it will be necessary to define the following terms:

Elasticity is the property of a body in which during a deformation of that body internal forces arise of such a nature as to tend to cause it to recover its original shape and size after the deforming forces are removed. The elastic strength or limit of such a body is the stress beyond which the deformation becomes permanent.

Hysteresis is the phenomenon whereby less energy is given out by a body in recovering from compression than is spent in its deformation, and results in a "set" of varying degree.

OBSERVATIONS

The findings can be divided into two groups: 1) those that concern the elastic properties of the discs; and 2) those that concern the compression of the discs. In each group graphs were prepared by plotting loads against deflections.
Elastic properties. Group 1. Loading to the elastic limit (Fig. 1)—In the experiments showing the "end point" of individual discs the curve was not unlike the yield point for steel except that when the "end point" was exceeded the disc still retained some power of recovery after rest. This power of recovery was very appreciably greater when the discs were immersed in a physiological fluid than when they were tested dry. The conclusion from this group of experiments is that the intervertebral disc holds the property of elasticity to a very marked degree. Moreover, the property of elasticity depends largely upon the ability of the intervertebral disc to absorb and lose fluid—it is in fact a viscous elasticity.

Group 2. Loads increased to 500 lb. and decreased again to 50 lb. (Fig. 2)—The curves rose sharply to a point and then fell during unloading at a slower rate, showing a loss of from 0.005 inch to 0.100 inch in height when a load of only 50 lb. was applied. From these curves it is possible mechanically to regard the intervertebral disc as a viscous elastic structure corresponding in a general way in its properties to organic substances which have a modulus increasing with load rather than a metal in which load and extension are proportional.

The hysteresis varied to a considerable degree, being smaller in the upper lumbar and lower dorsal discs, and larger in the lowest lumbar disc. It was greatly exaggerated in patients who had suffered from chronic passive congestion of the circulatory system, and in cases where Schmorl's nodes were well marked. The hysteresis also varied with age: in very young subjects the hysteresis was very large, in aged people where discs showed actual degeneration...
it was moderately large. It was least in people in the middle decade of life, and in subjects of the seventh decade in whom no degenerative changes were evident in the discs.

Group 3. Two successive tests on each disc (Fig. 3)—In these experiments it was demonstrated conclusively that the hysteresis during the second test was always appreciably less than that during the first test. In other words, the mechanical efficiency of the disc improved with use, and the energy lost during recovery became less. This is probably of significance in men doing heavy work, and provides a theoretical basis for the custom of "taking a strain" before a heavy load is lifted. "Taking a strain" is a physiological method of bringing the spine into an optimum state for severe stress.

The role of fluid exchange during compression and expansion of the disc requires further experimental investigation. However, the following facts were observed: during compression of dry discs, beads of moisture appeared on the disc in all cases when the load reached a level of about 300 lb.: the whole of the annulus fibrosus became wet, and even more fluid appeared at both cut surfaces and oozed out on to the plates of the machine: it was quite evident that deformation was accompanied by loss of fluid: in experiments on "wet" discs the Ringer's solution was absorbed appreciably by the specimen during its phase of recovery: without a supply of fluid recovery was imperfect.

The constant load experiments demonstrated that even with loads less than 50 lb. the disc was unable to maintain its height, but that the deformation was still very small after forty-eight hours' continuous load, and the disc recovered completely after the load was removed.

Effects of compression on the structure of the discs—Cracks or splits in the annulus fibrosus appeared under maximal loading. They extended from the top to the bottom of the disc, but were not usually associated with herniations from within the disc. Herniations of the disc material were produced on three occasions only, in spite of the heavy loads employed during the tests. It appears that herniations are relatively uncommon phenomena even under heavy stresses. They probably occur only in discs in which degenerative changes are fairly well advanced. When herniations occurred the tissue expelled through the split in the annulus fibrosus represented only a small proportion of the total contents of the disc.

Groups 4, 5, 6 and 7. Experiments into the effects of incision into the centre of the disc (Fig. 4)—Incisions were made through the postero-lateral part of the annulus fibrosus and were deepened into the central part of the disc to determine the effect upon its elastic properties. After a few experiments it was apparent that a mere linear incision or a split in the annulus, even when prolonged into the centre of the disc, caused no loss of its elastic properties (Fig. 4).
Nor was there any tendency for the contents of the discs to herniate through these splits. In order to produce any appreciable effect upon the elasticity of the disc it was necessary to make a U-shaped or Z-shaped incision in the annulus. Even in these circumstances herniations were not easily produced. There was definite interference with the recovery of the discs when U-shaped or angled incisions were used—the hysteresis was increased.

![Graph](image)

**FIG. 4**

Effect of a linear incision into the annulus fibrosus. Graph represents three loading tests each separated by an interval of one minute. Continuous line = first test; interrupted line = second test; dotted line = third test. A linear incision was made into the annulus fibrosus between the first and second tests. Note that the incision caused no loss of the elastic properties of the disc.

In four experiments whole sections of the spine were tested to observe the effects upon series of discs. The findings were essentially the same as for single discs. In each specimen the deflection was the sum of the deflections of the contained discs. In other respects also the behaviour of multiple segments of spine was similar to that of single discs. Angular incisions into the annulus of one of the discs in the segment caused interference with recovery, whereas simple linear incisions had no effect.

**CONCLUSIONS**

1. The intervertebral disc is an organic viscous elastic structure capable of maintaining very great loads without disintegration.
2. Recovery of the disc after deformation depends upon: a) the imbibition of tissue fluid by the disc, b) the removal of the deforming force. Complete recovery is modified by the duration of the force.
3. Factors that interfere with the elasticity of the disc are: extreme youth (immaturity of the disc), chronic wasting diseases (general nutritional disturbance), and local pathological changes in the bodies of the vertebrae which interrupt or damage its blood supply. The intervertebral disc reaches its greatest state of efficiency in adult life—that is, when the nucleus pulposus has disappeared as an entity. The function of the disc appears not to depend upon the presence of the nucleus: rather does the presence of the nucleus indicate immaturity of the disc.
4. The highly resilient elastic nature of the vertebral column is provided by the intervertebral discs, which constitute one-third of the whole length of the column.
5. The imbibition of fluid requires further investigation. It appears that from lacunae in the adjacent bodies finger-like pockets dip into the discs and that fluid passes through the lining membrane of these pockets.

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REFERENCES


