CHANGES IN THE MECHANICAL PROPERTIES OF INTERVERTEBRAL LUMBAR DISKS PRODUCED BY PROLONGED STATIC COMPRESSION FORCES*

V. E. Raikhinshtein, Ya. L. Tsiv'yan, and Ya. G. Ovseichik

UDC 611.71:539.3

Under modern conditions, the human vertebral column is most often the object of prolonged static compression forces. Many workers tend to regard chronic load as one of the etiological factors in vertebral pathology. In this regard, the determination of the functional resistance of the vertebral column to prolonged static compression is a very timely scientific and applied problem. This question has not yet been treated in detail. Almost all studies in experimental vertebrology have been carried out using brief stressing. In our previous studies [1-5], original methods were used to study the biomechanics of intervertebral disks under single-action, gradually increasing compression. These studies were the basis for the present work in which the intradisk pressure and tangential stretching of the annulus fibrosus were studied under vertical compression of lumbar spine specimens over many hours. In measuring the intradisk pressure, we obtained information on change in the mechanical properties of the inner element, the nucleus pulposus. By studying the tangential stretching of the annulus fibrosus, we investigated a mechanical index of the outer disk segment.

The specimens were blocks of the lumbar spine obtained in fresh medicolegal autopsies. Not more than 24–36 h elapsed from the moment of death to the time of the investigation. Preparations were made from the blocks which consisted of an intervertebral disk encased between adjacent vertebral bodies. The vertebral arches were cut at the root to eliminate the effect of dorsal structures of the vertebral column on the nature of the disk reaction. In all cases, the studies were carried out on the first to the fourth intervertebral disks. In the study of intradisk pressure, a total of specimens were prepared taken from the corpses of seven men and one woman, aged from 17 to 40. The study of the tangential stretching of the annulus fibrosus involved 42 disks taken from 11 corpses of individuals who died at ages from 17 to 70. All the disk studies were divided into three groups. Group I included completely unaltered disks without signs of macroscopic degeneration with a highly pronounced gel-like structure of the nucleus and elastic, defectless rings (26 disks). Group II consisted of disks with a moderately dense disk and unchanged ring (26 studies). Group III contained disks with a dense, fibrous, but uniform nucleus and friable ring with single slits (20 studies). The assignment of the specimens to these groups was made after the compression testing by taking a cross section of the disk. Grossly degenerated disks which had lost homogeneity of the nucleus and ring were not studied.


The intradisk pressure was measured using specially designed needle probes [1]. The experimental model was the following: the intradisk pressure was measured initially upon single-action, gradually increasing compression for each 50 kgf up to 200 kgf. Then, the sample was subjected to 6-h compression produced by a 200-kgf load and the intradisk pressure was measured every two hours and also one hour after the cessation of compression by the scheme presented above. In order to prevent drying out of the disk, the specimen was kept in a hermetically sealed container throughout the entire experiment. A run was terminated by measurement of the cross section of the disk studied for the calculation of the external pressure on the disk at all loads.

The measurement of the tangential stretching of the annulus fibrosus was carried out using a tensometric method developed in the Physiology Laboratory of the Novosibirsk Traumatology and Orthopedics Scientific-Research Institute [4]. The tensometric detectors were attached along the perimeter of the annulus fibrosus in strictly determined segments. The tangential stretching recordings were made in the same sequence as in measurements of the intradisk pressure, though not for every 50 kgf but for every 32 kgf with stepwise increments to 200-kgf compression.

Reaction of Intradisk Pressure to Prolonged Static Compression. With increasing duration of compression, a tendency was found for all specimens towards decreasing intradisk pressure. However, while this reduction in groups I and II was virtually proportional to the duration of compression (Fig. 1a), a significant decrease in intradisk pressure in the specimens of group III occurs after loading for two hours and no further reduction occurs upon additional exposure (Fig. 1b).

The maximum reduction in pressure was recorded at low loads of from 50 to 100 kgf. Thus, for group I specimens at 50-kgf load, the intradisk pressure before compression was on the average 6.7 ± 0.2 kgf/cm². After 2 h of loading it had already dropped to 5.6 ± 0.2 kgf/cm², i.e., by more than 27%. After 6 h the pressure had decreased to 5.1 ± 0.1 kgf/cm², i.e., by almost an additional 10%. On the other hand, at 200-kgf load, the decrease in intradisk pressure in the same specimens did not exceed 3% with increasing duration of compression for each two hours of load. It should also be noted that the decrease in the Intradisk pressure in moderately degenerated specimens (group III disks) by the effect of prolonged compression was less pronounced than in unaltered group I disks: by 7% for low loads from 50 to 100 kgf and by 4% for the maximum 200-kgf load.

As a consequence of different cross-sectional area and, thus, of different outer pressure on the disk at the same load, comparison of the absolute values of the intradisk pressure (in kgf/cm²) recorded in different specimens may cancel out true relationships. In this regard, we calculated and compared the ratios of the intradisk pressure (p₁) with the external pressure on the disk (pₑ) given in percentage. The average values of this index are given graphically in Fig. 2 for the compression process of specimens of the different groups. The curves show that the decrease in the percentage ratio in group I specimens occurs gradually during almost the entire course of compression. In group II specimens, the ratio gradually decreases until the fourth hour of compression and then does not undergo further significant change for the remaining two hours. In group III specimens, a marked decrease occurs in the first two hours of compression but the ratio is virtually invariant in the following four hours. In all specimen groups, a statistically significant decrease in the ratio could be found at low loads from 50 to 100 kgf. It is also characteristic that the intradisk pressure and its ratio to the external pressure did not return to the original values (prior to compression) in one hour after the cessation of compression in the specimens of all three groups. The extent of the decrease in this ratio was independent of the cross-sectional area of the disk and of the external pressure on the disk. A slight decrease in the ratio was noted in seven cases of 20 group I and II disks only by the sixth hour of load.

Tangential Stretching of the Annulus Fibrosus of Intervertebral Disks upon Prolonged Static Compression. A tendency was found in the upper lumbar disks for a reduction in the tangential stretching of the annulus fibrosus with increasing duration of the specimen stressing. This behavior is seen most clearly in the anterior segment of the ring. Thus, while the stretching of a segment was 12.7 ± 0.03 arbitrary units upon single-action loading at 32 kgf, it was 11.0 by 2 h and 9.5 ± 0.3 arbitrary units by six hours. An analogous effect was also observed at higher stress levels: stretching was 34.7 ± 0.5 arbitrary units upon single-action compression at 192 kgf, 32.2 ± 0.3 arbitrary units after 2 h exposure, and 30.2 ± 0.5 arbitrary units after 6 h.

A statistically significant (p < 0.1) reduction in the tangential stretching of the anterolateral and posterolateral segments was noted after 6-h loading relative to the values recorded upon single-action compression. Significant changes in the stretching at the compression stages after 2-4 h were not found.