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IN VIVO DISCOMETRY IN LUMBAR DISCS WITH IRREGULAR NUCLEOGRAMS

*Some Differences in Stress Distribution between Normal
and Moderately Degenerated Discs*

By

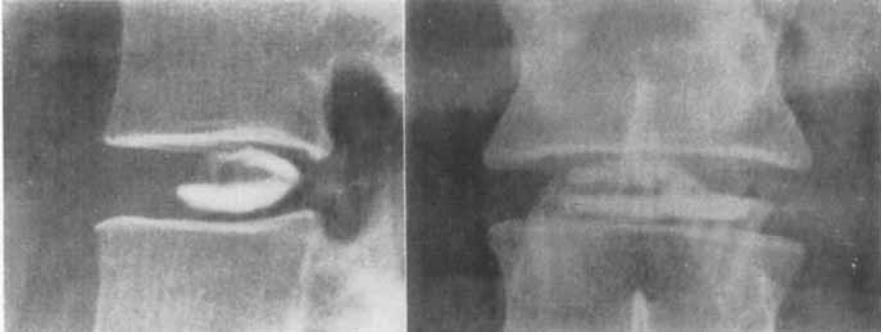
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Disc degeneration in the lumbar spine is often discussed in terms of mechanical factors inasmuch as they have been partially implicated in the etiology of morphological changes observed (1, 4, 5, 8, 9, 16).

Clinically the lumbar discs are mostly judged from standard radiograms of the lumbar spine and the roentgenographic changes interpreted as disc degeneration in the lumbar spine have been defined (10, 18). However, it has also been demonstrated by *Friberg & Hirsch* (5), that the degenerative changes inside the disc can exist in spite of a normal roentgenogram. Since disc degeneration in the lumbar spine also has been connected with symptoms of low back pain disorders (3, 7, 8, 9) other procedures *e.g.* disc puncture (*Hirsch*) (6) and discography (*Lindblom*) (11) have been added to the clinical and roentgenographic examination in patients with low back pain.

Today, discography or nucleography is a relatively frequently used procedure. When the nucleus pulposus shows a round, smooth-edged appearance without communications to the outside of the disc, it is regarded as normal (Fig. 1). If the nucleogram shows irregularities in its boundary with the annulus fibrosus or the vertebral endplate and if the contrast medium penetrates through the annulus fibrosus the disc has been said to be degenerated (2, 3, 11) (Figs. 2 and 3). *Erlacher* (2) classified the nucleographic picture in five different groups. It should be mentioned, however, that no definite knowledge exists as to the macroscopic anatomic equivalents of the irregular nucleograms.

Discometry is a method that evaluates the pressure inside lumbar

*Fig. 1.*

Normal discogram after completion of measurements.



a



b

Fig. 2.

Examples of nucleograms showing moderate degeneration of the nucleus pulposus.

Some fragmentation is seen, as well as the needle track.

- | | |
|----------------|------------------|
| A. Case No. 6 | (Male age 34 y.) |
| B. Case No. 10 | (Male age 40 y.) |

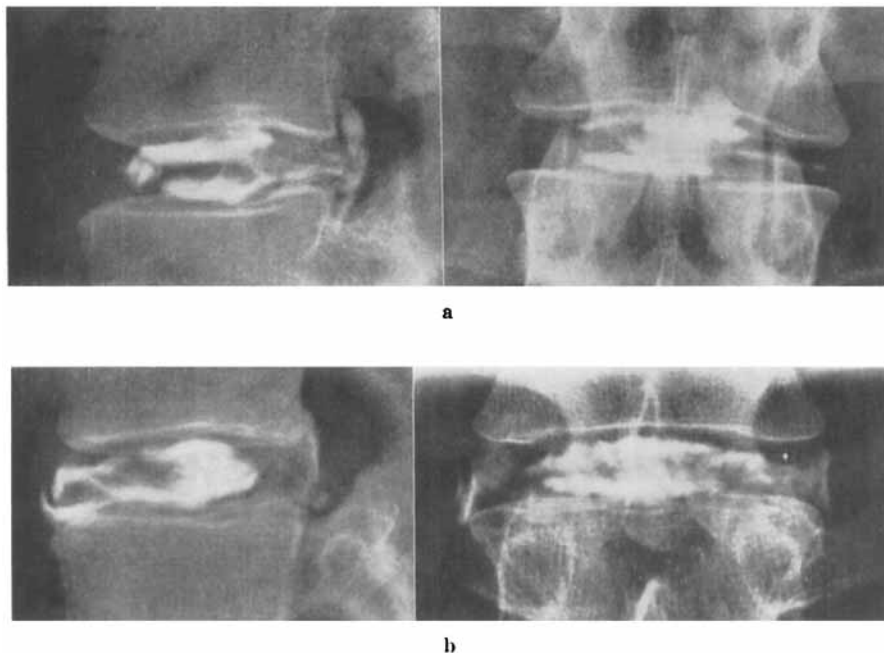


Fig. 3.

Examples of nucleograms showing moderate degeneration of the nucleus. In these discs the extent of fragmentation is more pronounced than in Fig. 2. A fissure can also be seen in the annulus fibrosus (B).

A. Case No. 7	(Male age 42 y.)
B. Case No. 9	(Male age 29 y.)

discs. This method was developed in autopsy material and was shown to be completely valid only in normal or slightly degenerated discs, as these discs were shown to have hydrostatic properties (12). Macroscopic examination alone was used to classify whether the disc was normal or not.

After the method had been established in post mortem material, studies were extended to living subjects (14, 15). The results of the *in vivo* tests could be categorized into three groups relative to the pressures recorded, when these were related to the size of the disc and the body weight of the patient.

In the first group the pressures were highest and the nucleogram performed at the completion of measurements was normal. In the second group the stresses recorded were lower and the nucleograms all showed some fragmentation of the nucleus and occasional fissure

TABLE 1
Summary of Data on Subjects.

Case No.	Age yr.	Sex	Weight kg	Height cm	Level	Disc.	
						Condition	History
1	58	♂	66.8	165	L3	Mod. degen.	Low back pain for 6 yrs.
2	53	♂	80.3	170	L3	"	Lumb. scoliosis due to short leg. Low back pain.
3	43	♂	58.3	180	L3	"	Fusion L4-S1. Back pain.
4	39	♀	85.0	165	L4	"	Low back pain and sciatica.
5	43	♀	64.0	173	L2	"	Mild low back pain 3 months.
6	34	♂	72.6	180	L3	"	Low back pain for 2 weeks.
7	42	♂	80.0	179	L3	"	Low back pain for 6 months.
8	40	♂	83.0	184	L3	"	Low back pain for 7 months.
9	29	♂	74.5	183	L3	"	Low back pain for 2 months.
10	40	♂	81.0	180	L3	"	Mild low back pain 3 weeks.

TABLE
Stresses Obtained in Moderately Degenerated Discs

Case No.	Disc area cm ²	Disc level	Part of bodyw. above level kg*	Sitting un_supp. upright	Sitting Valsalva maneuver	Sitting corset inflated	Sitting 9.1 kg in hands
1	17.7	L3	38.1	6.9	7.7		7.4
2	18.1	L3	45.8	9.2	10.2	4.2	13.0
3	15.0	L3	33.2	8.5			12.8
4	15.8	L4	50.2	11.3	11.3	7.7	14.4
5	16.3	L2	35.2	7.4			
6	20.4	L3	41.4	7.7			
7	17.5	L3	45.6	12.8			
8	21.1	L3	47.3	6.7			
9	17.8	L3	42.5	7.4			
10	22.2	L3	46.2	4.9			

§ 31.8 kg added. † 10° forward leaning only.

* According to *Ruff* (17).

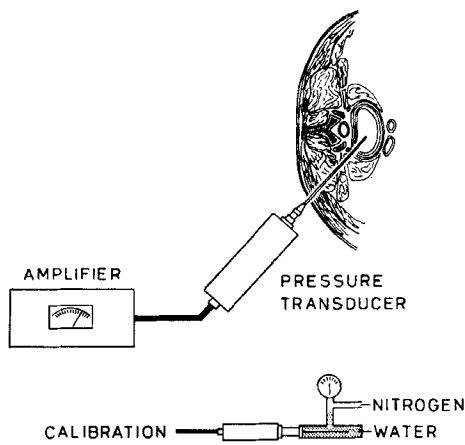


Fig. 4.

Schematic drawing of the method used in intravital disc pressure measurements (discometry). The manner by which the needle is inserted is also demonstrated.

formation in the annulus. Repeated measurements in these individuals yielded reproducible results.

In the third group the pressure recordings were lowest and varied considerable and were non-reproducible. In this group the nucleograms showed marked irregularities and fissures in the annulus fibrosus.

2

under Various Conditions (in Kg per cm²).

Sitting 22.7 kg in hands	Sitting forward leaning 20°	Sitting forward leaning 10 kg in hands	Sitting forward leaning 20 kg in hands	Reclining tilted on side	Standing upright	Standing forward leaning 20°
12.1§						
15.5				7.0		
16.3				7.0		
19.0				5.8		
	8.7	10.9	13.4	5.3	6.3	8.1
	9.2†	10.2†	12.7†			
	8.8					
	13.0	15.1	18.0	3.5	5.8	10.6

The results of the discometry studies in the first group have been previously reported (15). This report presents the results of intravital discometry in discs where the nucleogram showed some fragmentation and/or a fissure in the annulus, and in which the recordings were reproducible.

METHOD

The method by which the stresses are evaluated has been reported elsewhere (12, 15). It is based on the fact that the nucleus pulposus acts on a membrane-covered, water-filled needle having a rectangular hole in its side. This needle is connected to a pressure transducer (Fig. 4). Before and after each experiment the needle is calibrated against known pressures. By the use of the roentgen image intensifier it is easy to locate the disc to be tested. The needle is inserted in L:2, L:3 or L:4 discs from the side. It should be noted that each stress value recorded is a mean from three consecutive measurements, where each single measurement has not deviated from the mean more than comparable recordings in the fully normal discs (15).

MATERIAL

Ten subjects where the nucleograms fulfilled the criteria outlined were studied. The vital data are summarized in Table 1. The subjects were tested in different positions due in part to technical circumstances and also to the fact that the subjects were evaluated at different periods when one or the other special position was being studied. These data are presented in Table 2.

RESULTS

Sitting Position

As seen from Table 2 the stresses measured ranged from 5 to 13 kg/cm² in the sitting position used in the studies *i.e.* straight upright sitting with arms resting along the sides of the body and without back support.

On average, the stresses measured were 30 per cent less than would have been expected for an individual of the same size and with the same cross-sectional area of the disc but with a normal nucleogram (Table 3).

From values obtained with weights in the hands, both upright and leaning forward, it is obvious that even in these discs with somewhat irregular nucleograms the stresses increase in the same manner as was noted in discs with normal nucleograms (14).

Standing Position

The results tend to confirm earlier observations on nucleographically normal discs that the stress inside the discs and accordingly, the load on the disc decreases by about one third as compared to the sitting position used (Table 2). The stresses obtained in the discs reported here were, as in the sitting position, about 30 per cent less than might be expected.

Reclining Position

The five measurements performed in reclining position (lateral decubitus) also showed lower values of stress in these discs than in nucleographically normal discs. Compared to the values recorded in the same discs in the sitting position a decrease averaging 50 per cent was noted (Table 2). The same observation was made earlier (15).

DISCUSSION

In autopsy studies it was shown that even when the disc was classified as somewhat degenerated at macroscopic examination the nucleus still retained its hydrostatic properties (12). These discs showed some fibrosis in the nucleus and/or isolated fissures in the annulus. It appears that such changes exist in the discs presented here, where the nucleograms showed irregularities and the results were reproducible. These results therefore can be regarded as obtained from discs with macroscopic degenerative changes, probably, however, of a mild degree.

TABLE 3
Stresses Obtained in moderately Degenerated Discs Compared with Expected Values of Disc Pressure in Normal Discs.
 Upright sitting position

Case No.	Stress measured kg/cm ²	Disc area cm ²	Bodyweight above level measured kg	Total load kg	Load on disc kg/cm ²	Approx. pressure in a normal disc kg/cm ²	Decrease in stress in deg. disc as compared to normal %
1	6.9	17.7	38.1	136.7	7.7	11.6	41
2	9.2	18.1	45.8	158.2	8.7	13.1	30
3	8.5	15.0	33.2	123.0	8.2	12.3	30
4	11.3	15.8	50.2	170.6	10.8	16.2	30
5	7.4	16.3	35.2	128.6	7.9	11.9	38
6	7.7	20.4	41.4	145.9	7.2	10.7	28
7	12.8	17.5	45.6	157.7	9.0	13.5	5
8	6.7	21.1	47.3	162.4	7.7	11.6	42
9	7.4	17.8	42.5	149.0	8.4	12.6	41
10	4.9	22.2	46.2	159.4	7.2	10.8	55
							m 34%

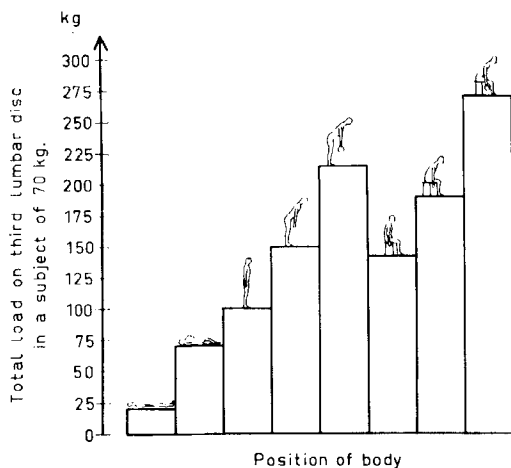


Fig. 5.

Total load on the third lumbar disc in different positions in a subject weighing 70 kg. Positions shown are 1) reclining (relaxed, supine), 2) reclining (lateral decubitus), 3) standing upright, 4) standing + twenty degrees forward leaning without and 5) with 20 kg load in arms, 6) sitting upright, arms and back unsupported, 7) sitting + twenty degrees forward leaning, without and 8) with 20 kg load in arms.

TABLE 4

Approximate Formulas for Load (P) on Lumbar Discs in Different Positions.

P_O = intrinsic pressure. W = weight above the level measured.
(59% of bodyweight above L: IV, 57% above L: III and 55% above L: II.)

Position.

Upright sitting with arms and back unsupported	$P_{\text{sitt.}} = P_O + 2.8W$	; $P_O \approx 30 \text{ kg}$
Upright standing	$P_{\text{stand.}} = P_O + 2.1W$	; $P_O \approx 15 \text{ kg}$
Reclining (tilted on side, lateral decubitus)	$P_{\text{recl.}} = \frac{P_O + 2.8W}{2}$	; $P_O \approx 30 \text{ kg}$
Reclining (relaxed, supine)	$P_{\text{recl.}} = P_O$	; $P_O \approx 15 \text{ kg}$
Sitting + forward leaning α degrees	$P_{\text{sitt.}} = P_O + 2.8W + 3.6W \sin \alpha$	; $P_O \approx 30 \text{ kg}, \alpha = 10-20^\circ$
Standing + forward leaning α degrees	$P_{\text{stand.}} = P_O + 2.1W + 3.6W \sin \alpha$	; $P_O \approx 15 \text{ kg}, \alpha = 10-20^\circ$

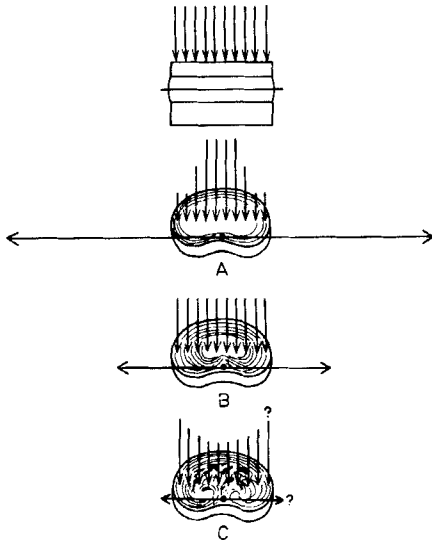


Fig. 6.

Relative relationship between load on the lumbar disc per unit of area and the vertical and tangential stresses on the annulus fibrosus.

A. Normal disc.

B. Moderately degenerated disc.

C. Severely degenerated disc. (Hypothetically, cannot be measured with the present method.)

From the discometry studies in discs with normal nucleograms, the approximate relationship between the body weight of the subject, his position and the total load on the disc could be delineated (Fig. 5) (14, 15). These relationships are tabulated in Table 4.

In Table 3 the stresses measured in the sitting position in subjects with moderately degenerated discs is shown. The total load on the disc is calculated according to the formula given in Table 4. Dividing this load by the cross-sectional surface area of the disc, the load on the disc per unit of area can be obtained. It is seen in Table 3 that this load per unit of area is approximately equal to the stress measured inside these discs.

In the normal discs it was found that the pressure measured in the nucleus pulposus is 1.5 times the load applied per unit of area (12, 13). In discs with irregular nucleograms the stress measured under intravital conditions is equal to the load on the disc per unit of area (Table 3). This implies that one effect of a moderate degeneration seems to be a decrease of about 30 per cent of the intradiscal stress.

From earlier studies (12, 13) on autopsy specimens a relationship between the pressure or stress in the nucleus pulposus and the vertical and tangential, tensile stresses in the dorsal part of the annulus fibrosus was established (Table 5, Fig. 6). In macroscopically normal lumbar discs taken at autopsy the width is approximately 6 mm. In these discs

TABLE 5

Approximate Relationship between Load per Unit of Area (p) on the Disc and the Intradiscal Pressure Measured (p_n).

Normal discs:	$p_n = 1.5p$
Moderately degenerated discs:	$p_n = p$

Approximate Relationship between Vertical Load on the Annulus Fibrosus (p_a) and the Vertical Load per Unit of Area (p) in the Disc.

Normal discs:	$p_a = 0.5p$
Moderately degenerated discs:	$p_a = p$

Approximate Relationship between the Tangential, Tensile Stress in the Dorsal Part of the Annulus Fibrosus (δ_{td}) and the Load per Unit of Area on the Disc (p) and the Intradiscal Pressure (p_n).

Normal discs:	$\delta_{td} = 4p = 2.7p_n$
Moderately degenerated discs:	$\delta_{td} = 2p = 2p_n$

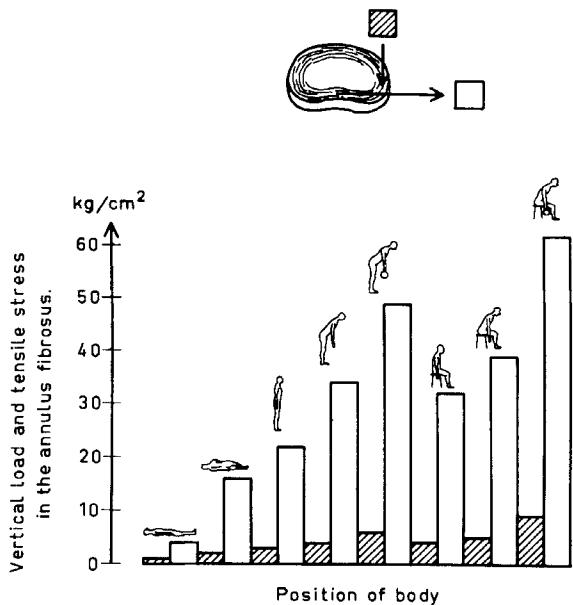


Fig. 7.

Vertical load per unit of area on the annulus fibrosus and tangential, tensile stress in the dorsal part of the annulus in a normal third lumbar disc in a subject weighing 70 kg and assuming the positions schematically shown (see Table 6). In the moderately degenerated disc the vertical stress will increase by 100 per cent and the tangential, tensile stress decrease by 50 per cent.

the tangential, tensile stresses (δ_{td}) could be calculated from the expression:

$$\delta_{td} = 4 p.$$

where p is the load per unit of area on the disc (Table 5).

In the normal discs the vertical load on the annulus was found to be only 50 per cent of the applied load per unit of area on the disc. In the moderately degenerated discs, presented here, however, where the stress inside the nucleus has decreased by one third, as compared to normal discs, the vertical load on the annulus will be about the same as that applied on the disc per unit or area (Table 5).

TABLE 6

Approximate Vertical Load and Tangential, Tensile Stress in the Dorsal Part of the Annulus Fibrosus in a Subject Weighing 70 kg, with a Moderately Degenerated Third Lumbar Disc Having Cross-Sectional Area of 17.5 cm². Comparable Values in a Normal Disc are Given

Position of body	Moderately degenerated		Normal	
	Vertical load kg/cm ²	Tensile stress kg/cm ²	Vertical load kg/cm ²	Tensile stress kg/cm ²
Upright sitting, unsupported	8	16	4	32
Upright standing	6	11	3	22
Reclining (lateral decubitus)	4	8	2	16
Reclining (relaxed supine)	2	2	1	4
Sitting + forward tilting of 20°	10	22	5	44
Sitting + forward tilting of 20° and 10 kg load in each hand	15	31	8	62
Standing + forward tilting of 20°	8	17	4	34
Standing + forward tilting of 20° and 10 kg load in each hand	12	24	6	49

Using the established equations (Tables 4 and 5) the approximate vertical load and tangential, tensile stress on the dorsal part of the annulus fibrosus in subjects of different weights can be calculated for normal lumbar discs (Fig. 7).

This can be done also in the present material and it can be shown that moderate degeneration probably implies an increase by about 100 per cent for the vertical load on the annulus fibrosus while the tangential, tensile stresses decrease by 50 per cent when compared to the normal discs. Thus the change in stress distribution that occurs in lumbar discs with irregular nucleograms can be mathematically expressed. Schematically this is visualized in Fig. 6. In Table 6 these stresses have been calculated for lumbar discs of equal size with normal and irregular roentgenograms in a subject of 70 kg.

As was mentioned, it is very likely, that the material presented here, discs with nucleograms showing some irregularities, is comparable to the macroscopic picture of moderate degeneration, *i.e.* some fibrosis in the nucleus and an occasional fissure in the annulus. The reason for the lower stress values obtained in these discs where hydrostatic properties still exist might be either that the substance of the nucleus pulposus has changed to that it is now more easily compressible or else that the stiffness of the annulus fibrosus has increased *i.e.* in the normal discs the annulus is more easily compressed vertically than in the degenerated discs.

S U M M A R Y

Results are reported from intravital discometry in ten individuals, where the lumbar discs measured showed some fragmentation of the nucleus and an occasional fissure in the annulus fibrosus in the nucleogram performed at the completion of measurements. Since no definite knowledge exists as to the macroscopic anatomic equivalent of defined nucleograms it is for the moment impossible exactly to evaluate the degree of degeneration of the discs in this material. For reasons discussed in the paper the present material most likely represents lumbar discs with macroscopically moderate degeneration.

Moderate degeneration in the lumbar disc seems to lessen the internal stress by about 30 per cent as compared to the pressures obtained in nucleographically normal discs of equal sizes and in individuals of the same body weight.

The values obtained in the unsupported upright sitting position have been around 10 kg/cm² (5–13 kg/cm²). Recordings in subjects holding

weights with and without forward leaning showed increases of the stresses in the same manner as was observed in the normal discs.

In the standing and reclining positions studied the values recorded implied a decrease of 30 and 50 per cent respectively, as compared to the sitting position used. The same decrease in pressure was noted in normal discs.

Moderate degeneration in a lumbar disc will change the distribution of stress compared to a normal disc so that the vertical load on the dorsal part of the annulus fibrosus will increase by 100 per cent while the tangential, tensile stress in the same part will decrease by 50 per cent.

It could be calculated that the vertical load on the annulus fibrosus in a man of 70 kg, having a moderately degenerated third lumbar disc, would be 10 kg/cm² in the 20° forward sitting position, as compared to 5 kg/cm² were the disc normal.

The tangential, tensile stress in the dorsal part of the third lumbar disc in such a subject would be about 30 kg/cm² if the disc was moderately degenerated and about 60 kg/cm² were the disc normal.

Increased compressibility of the nucleus pulposus and/or increased stiffness in the vertical direction of the annulus fibrosus in these discs as compared to nucleographically normal ones might account for the lower values of stress obtained in the nucleus pulposus.

RESUME

Sont rapportés les résultats de discométrie intravitale chez 10 individus où les disques lombaires mesurés montraient une fragmentation du noyau et une fissure occasionnelle de l'anneau fibreux sur le nucléogramme pratiqué pour compléter les mensurations. Etant donné que l'on n'a pas des connaissances définitives sur l'équivalence anatomique macroscopique de nucléogrammes déterminés, il est pour le moment impossible d'évaluer exactement le degré de dégénération des disques dans ce matériel d'observation. Pour des raisons données dans cette étude, le présent matériel d'observation présente probablement des disques lombaires avec une dégénération macroscopique modérée.

Une dégénération modérée du disque lombaire semble diminuer la tension interne d'environ 30 pour cent par comparaison avec la pression obtenue dans les disques nucléographiquement normaux d'égale grandeur chez des individus ayant le même poids du corps.

Les valeurs obtenues dans la position assise redressée sans support

ont été d'environ 10 kg/cm^2 ($5\text{--}13 \text{ kg/cm}^2$). Des enregistrements chez des sujets tenant des poids en position inclinée en avant ou non montrent une augmentation de la tension de la même manière que celle observée pour les disques normaux.

Dans les positions verticale et couchée, l'étude des valeurs enregistrées montre une diminution de 30 à 50 pour cent respectivement, comparées à la position assise utilisée. La même diminution de la pression dans les disques normaux a été constatée.

Une dégénération modérée du disque lombaire change la distribution de la tension par rapport aux disques normaux de sorte que la charge verticale sur la partie dorsale de l'anneau fibreux augmente de 100 pour cent, alors que la force tangentielle de tension diminue de 50 pour cent environ dans la même partie.

On a pu calculer que la charge verticale sur l'anneau fibreux chez un homme de 70 kg ayant le 3ème disque lombaire légèrement dégénéré serait de 10 kg/cm^2 en position inclinée en avant de 20° par comparaison à 5 kg/cm^2 pour un disque normal.

La tension tangentielle dans la partie dorsale du 3ème disque lombaire chez un tel sujet serait de 30 kg/cm^2 si le disque est légèrement dégénéré et approximativement de 60 kg/cm^2 si le disque est normal.

Une compressibilité accrue du noyau fibreux et/ou une rigidité accrue en direction verticale du noyau fibreux dans ces disques, par comparaison avec ceux nucléographiquement normaux, peut provenir des valeurs inférieures de tension obtenues dans le noyau pulpeux.

ZUSAMMENFASSUNG

Über Ergebnisse intravitaler Diskometrie an zehn Personen, bei denen die gemessenen lumbalen Zwischenwirbelscheiben etwas Fragmentierung des Nucleus und gelegentlich eine Fissur des Annulus fibrosus im Nukleogramm, das bei der Vollendung der Messungen ausgeführt wurde, zeigten, wird berichtet. Da keine sichere Kenntnis hinsichtlich des makroskopisch-anatomischen Equivalentes eines eindeutigen Nukleogramms besteht, ist es zur Zeit unmöglich den Grad der Degeneration der Zwischenscheibe in diesen Materiale zu bestimmen. Aus Gründen, die in der Arbeit besprochen werden, stellt das vorliegende Material höchst wahrscheinlich lumbale Zwischenwirbelscheiben mit makroskopisch moderater Degeneration dar.

Moderate Degeneration in der lumbalen Zwischenwirbelscheibe scheint die innere Spannung um ungefähr 30 Prozent zu vermindern im

Vergleich zu den Druckwerten, die man in nukleographisch normale Scheiben von gleicher Grösse und bei Personen gleichen Körpergewichtes erhält.

Die Werte, die bei nicht unterstützter, aufrecht sitzender Stellung erhalten wurden bewegen sich um 10 kg/cm^2 ($5\text{--}13 \text{ kg/cm}^2$). Aufzeichnungen an Personen, die Gewichte hielten, mit und ohne Vorwärtsbeugung, zeigten eine Zunahme der Druckwerte in derselben Weise wie sie bei normalen Scheiben beobachtet wurde.

Bei der Untersuchung in stehender und liegender Stellung wiesen die aufgezeichneten Werte auf eine 30 Prozent, beziehungsweise 50 Prozent Abnahme hin. Dieselbe Abnahme des Druckes wurde bei normalen Scheiben bemerkt.

Mässige Degeneration einer Lendenwirbelzwischen Scheibe wird die Druckverteilung im Vergleich mit der normalen Scheibe verändern u.zw. derartig dass die vertikale Belastung am dorsalen Teil des Annulus fibrosus um 100 Prozent zunehmen wird, während der tangentielle Spannungsdruck derselben Region um 50 Prozent abnehmen wird.

Man könnte ausrechnen, dass die vertikale Belastung auf den Annulus fibrosus bei einem 70 kg schweren Mann mit mässig degeneriertem drittem Lendendiskus 10 kg/cm^2 bei 20° vorwärts geneigter Stellung sein würde, während sie nur 5 kg/cm^2 beim normalen Diskus sein würde.

Der tangentielle Spannungsdruck im dorsalen Teil der dritten Lendenscheibe einer solchen Person würde ungefähr 30 kg/cm^2 sein, wenn der Diskus moderat degeneriert wäre und ungefähr 60 kg/cm^2 wenn er normal sein würde.

Erhöhte Zusammendrückbarkeit des Nucleus pulposus und/oder vermehrte Steifheit des Annulus fibrosus dieser Zwischenscheiben in der vertikalen Richtung können, im Vergleich mit nukleographisch normalen Disken, für die niedrigen Druckwerte im Nucleus pulposus verantwortlich gemacht werden.

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