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The relationship between height, shape and histological changes in early degeneration of the lower lumbar discs

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Abstract The influence of aging and early degenerative changes on intervertebral disc height is controversial. It has been claimed that with aging, narrowing of the disc is inevitable, but this is not confirmed by some published radiological investigations. The present study analysed the height and shape of intervertebral discs from subjects younger than 40 years, and correlated the findings with histological alterations, which were assessed using a grading system. Discs from the L4/5 level (n = 13) and the L5/S1 level (n = 10) were included. Degenerative changes tended to increase with age, specifically at the L4/5 level. There was a weak trend towards decreased disc height with increasing degenerative changes, but no significant correlation could be found. Disc shape was more convex in the frontal than the sagittal plane. It is concluded that early histological changes do not significantly influence intervertebral disc height. More pronounced loss of disc height may be seen in advanced degenerative changes or in elderly subjects.

Key words Lumbar spine · Disc · Disc height · Degeneration · Histological changes

Introduction

The height of an intervertebral disc is influenced by several factors. Reversible height changes are observed diurnally, with a high intradiscal osmotic pressure being dynamically balanced against the compression forces on the disc [2]. Under load, the disc loses water, with an increasing concentration of sodium and potassium ions. The increase in electrolyte concentration acts as an osmotic reabsorption force and with load reduction disc volume and height is restored [13]. Irreversible loss of disc height may be found with the reduction of disc tissue volume, for example in cases of disc herniation [21]. Experimentally, the height reduction is proportional to the amount of tissue removed [6].

The age of the subject and the grade of disc degeneration also influence the disc height. Both factors are closely related, as the incidence and degree of disc degeneration increase considerably with age. Due to their position at the lordotic apex the lower lumbar discs are mainly affected [8]. A reduction of the intervertebral disc height with age is thought to be inevitable [24], although radiological studies failed to confirm this disc narrowing, especially in patients with relatively minor degenerative disc changes. In contrast, an increase in disc height until the fifth decade and more pronounced bulging of the disc towards the endplate have been reported [3, 22]. However, inaccuracy of the analytical method and interobserver variability of the measurements from plain lateral radiographs must be taken into account [4, 19].

In the present study, height and shape of lower lumbar discs were measured directly from tissue sections and the findings were correlated with histological changes, which were classified using a specific grading system. Specimens from donors less than 40 years old were chosen in order to account for early disc changes.

Table 1 Sagittal disc height (mm) and grade of histological degeneration (scale 1–4) in lower lumbar discs of subjects less than 40 years old

			L4/5				L5/S1			
#	Age	Sex	Anterior	Middle	Posterior	Grade	Anterior	Middle	Posterior	Grade
385	17	f	10.6	9.8	7.4	2.3	–	–	–	–
293	30	f	14.4	11.4	7.4	2.2	13.5	9.8	6.3	2.8
319	31	f	12.5	10.5	7.5	2.3	14.5	10.5	7.5	2.8
261	32	f	8.2	10.6	11.8	3.0	–	–	–	–
068	35	f	12.6	9.4	8.6	2.9	10.8	9.0	7.2	2.5
510	37	f	13.0	10.2	8.5	3.2	12.8	9.4	7.8	3.2
508	20	m	15.0	9.6	8.0	3.2	15.0	9.7	10.0	3.3
314	24	m	11.4	9.1	8.2	2.1	13.2	9.5	8.0	2.3
412	27	m	15.0	9.8	7.3	3.4	7.8	4.8	3.5	2.8
292	30	m	10.0	8.8	4.5	3.3	11.5	7.3	4.3	3.3
297	35	m	–	–	–	–	13.5	9.0	8.3	2.7
024	31	m	12.2	7.2	5.3	2.9	–	–	–	–
311	37	m	14.8	14.2	9.6	3.7	–	–	–	–
098	38	m	15.0	11.4	7.6	3.0	14.5	9.0	5.3	3.0

Material and methods

The study included 13 L4/5 and 10 L5/S1 disc specimens from 14 subjects under the age of 40 years (average 30.3 years, Table 1). Six were women and eight were men. Low back pain was not apparent in the case history of any of the subjects.

Lumbar spines were removed at autopsy and fixed in 10% buffered formalin for 1 week. Individual lower lumbar motion segments were prepared by transecting the vertebrae in the midaxial plane with a bandsaw. The blocks were immersed in a solution comprising 10% (v/v) nitric acid and 1% (w/v) EDTA until complete decalcification was confirmed by radiography. After removal of the posterior elements in the disc untis were cut into multiple parasagittal slices approximately 5 mm thick. All slices were processed into paraffin wax using standard methods, and tissue sections of 5 μm thickness were stained by haematoxylin and eosin for histological examination. For each level three disc sections, representing the mid-sagittal, left-sagittal and right-sagittal areas of the disc, were measured and histologically analysed. The method of choosing the appropriate sections is illustrated in Fig. 1. The distance between the analysed central and peripheral sections was therefore about 10 mm.

Based on previous descriptive studies the histological changes were classified according to the grading system outlined in Table 2, which was specifically designed to describe early degenerative changes [5, 18, 24]. The grade of each single section was obtained by calculating the mean of all four categories, and the final grade was the average of all three sections.

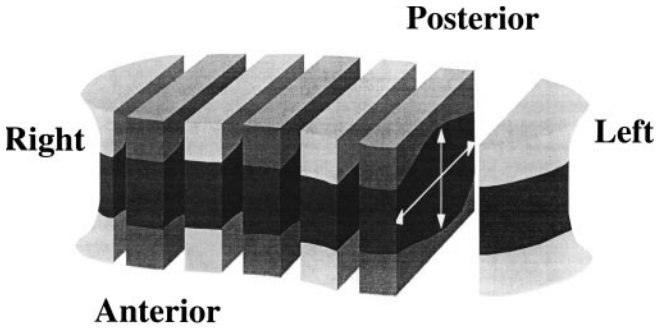

Fig. 1 Schematic diagram showing the parasagittal slices taken from each specimen for histology and measurement of disc height, anteroposterior diameter and convexity index. Sections in darker grey were used for measurements

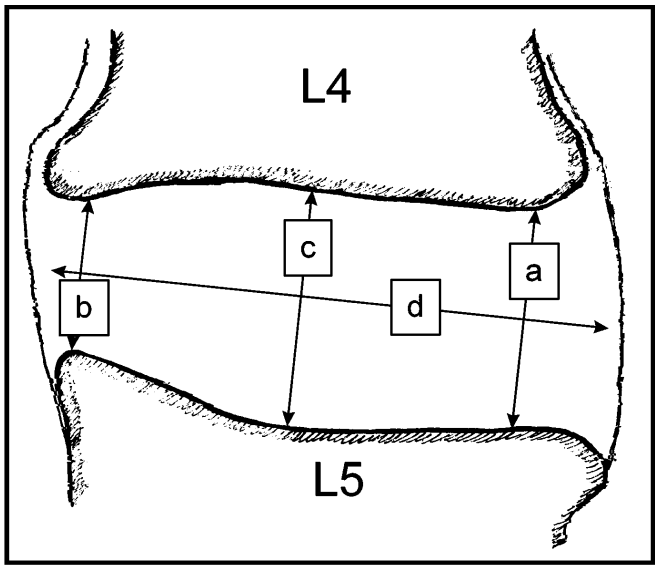

Fig. 2 Schematic diagram according to Fig. 3, showing the measurements of disc heights. Anterior (**a**) and posterior (**b**) disc heights are taken at local "minima" at the peripheral endplates, the central disc height (**c**) is measured at the local "maximum". All heights are taken perpendicular to the sagittal diameter (**d**), which is measured between the outer annular fibres

The disc height in the sagittal plane was measured anteriorly, centrally and posteriorly between the adjacent endplates (Figs. 1, 2). The anteroposterior (AP) diameter was measured between lines drawn from the endpoints of the superior vertebral endplate to the inferior, which was usually equivalent to the distance between the outer anterior and posterior annular regions. The Farfan index {[(anterior + posterior disc height)/AP diameter]*100}, was calculated to express relative disc height, using the average measurements from the three sections.

Table 2 Grading system of histological changes in lower lumbar discs (*BEP* bony endplate, *CEP* cartilaginous endplate)

Grade	Annulus fibrosus	Nucleus pulposus	Endplate	Margins/subchondral bone
1	Intact lamellae Narrow interlamellar matrix Intact annulus attachment Vessels only in outer 1/3	Homogeneity Absence of clefting	Uniform thickness Intact attachment to bone Uniform calcification < 1/5 of depth Uniform cell distribution	Even thickness of BEP Lamellar bone only Distinct junction with CEP Few vascular intrusions into CEP
2	Minor lamellar splitting and disorganization Minor widening of matrix Minor disorganization of attachment Rim lesion without reparative reaction	Minor clefting Minor cell necrosis Minor posterior displacement of annulus Minor chondrone formation	Minor cartilage thinning Small transverse fissures Irregular thickening of calcified zone Few invading vascular channels Small chondrones	Slightly uneven BEP Schmorl's nodes Minimal remodelling of BEP Small marginal osteophytes
3	Moderate lamellar disorganization Moderate widening of matrix Moderate fissuring of attachment Radiating tears, not involving outer 1/3 Minimal chondroid metaplasia Cystic degeneration Vessels in outer and middle 1/3 Rim lesion with minor reparative reaction	Moderate clefting Moderate cell necrosis Cystic degeneration Posterior displacement within annulus Centripetal extension of collagen Moderate chondrone formation	Marked cartilage thinning Marked thickening of calcified zone Many transverse fissures Many vascular channels Many chondrones	Moderately uneven BEP Vascularized Schmorl's nodes Moderate trabecular thickening Defect in bone lamellae Minimal fibrous tissue in marrow spaces Medium-sized osteophytes
4	Extensive lamellar disorganization Radiating tears extending into outer 1/3 Extensive chondroid metaplasia Vessels in all zones Rim lesion with marked reparative reaction	Complete loss of nucleus Loose body formation Marked chondrone formation	Total loss of cartilage Calcification of residual cartilage Widespread fissuring	Marked uneven BEP Ossified Schmorl's nodes Large osteophytes Marked trabecular thickening Marked fibrosus of marrow spaces Cartilage formation

The disc convexity in the sagittal and frontal plane was assessed using a convexity index, again using the average measurements from the three sections (Fig. 1). For the sagittal convexity index the central disc height was divided by the sum of the anterior and posterior disc heights [22]. The frontal convexity index was calculated accordingly, comparing the average height measurements of the three histological sections.

The correlation of Farfan index and disc convexity with subject age and grade of disc degeneration was assessed for both levels. For statistical analysis, regression analysis was used.

Results

Apart from one disc at the L4/L5 level, all discs were found to be wedge shaped with the largest height measured anteriorly. At the L4/5 level, the average disc height anteriorly was 12.7 mm (SD 2.18), centrally 10.2 mm (SD 1.65) and posteriorly 7.8 mm (SD 1.79). At the L5/S1 level the average disc height anteriorly was 12.7 mm (SD 2.17), centrally 8.8 mm (SD 1.63) and posteriorly 6.8 mm (SD 1.98). The average difference between anterior and posterior height in one disc was 5.6 mm (range 3.2–7.7 mm) at the L4/5 level and 5.9 mm (range 3.6–9.2 mm) at the L5/S1 level. The average AP disc diameter was 30.4 mm (SD 3.67) at L4/5 and 28.6 mm (SD 2.98) at L5/S1. The average Farfan index measured 67.2 (SD 7.13) at L4/5 and 69.0 (SD 13.13) at L5/S1.

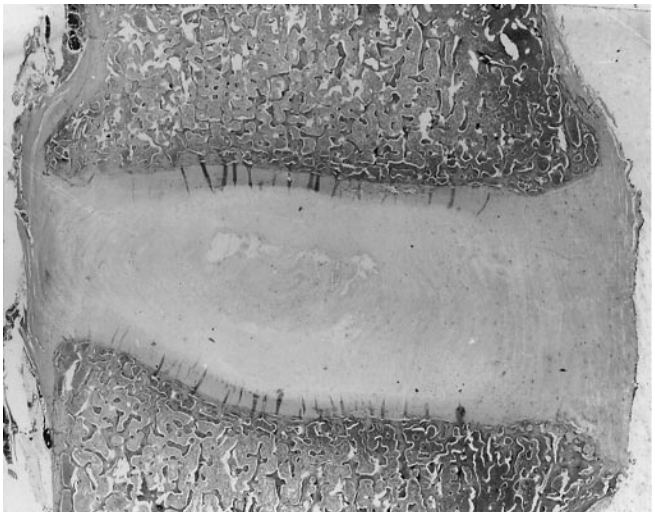

Fig. 3 Histological section of L4/5 disc, showing minor degree of convexity and minimal wedge shape

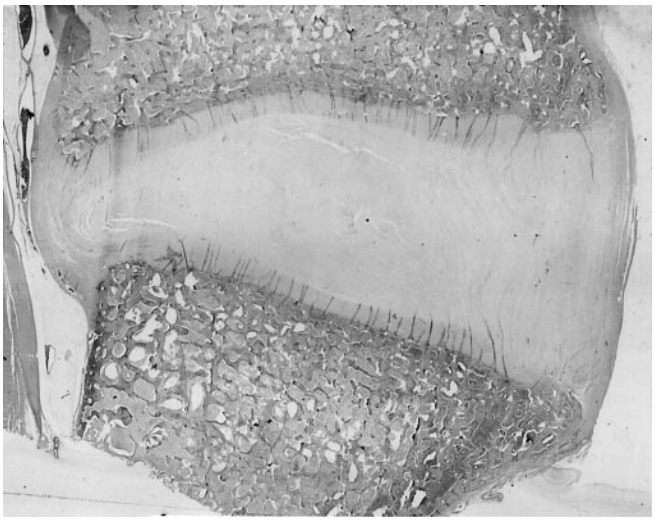

Fig. 4 Histological section of L5/S1 disc, showing a more pronounced degree of convexity and wedge shape

Table 3 Indices of disc convexity in the sagittal and frontal plane. Average (SD) given for all discs

	Sagittal				Frontal	
	Left	Middle	Right	Anterior	Middle	Posterior
L4/5	0.52 (0.10)	0.52 (0.08)	0.44 (0.12)	0.51 (0.08)	0.57 (0.10)	0.51 (0.07)
L5/S1	0.45 (0.04)	0.47 (0.08)	0.46 (0.07)	0.58 (0.12)	0.58 (0.12)	0.56 (0.11)

At both levels, the average grade of disc degeneration was 2.87 (SD L4/5: 0.51, L5/S1: 0.35). The histological grading of the three sections analysed per disc were found to differ maximally by one grade. At L4/5 changes of grade 3–4 were the most frequent finding (seven discs), followed by grade 2–3 changes (six discs). At the L5/S1 level grade 2–3 changes were observed in six discs and grade 3–4 changes in four. The complete findings for each disc are shown in Table 1.

Convexity of the disc was more pronounced at the L4/5 level (Fig. 3) that at L5/S1 (Fig. 4) and more pronounced in the frontal plane than in the sagittal plane (Table 3).

There was no significant correlation between the Farfan index, the subject's age and the extent of disc degeneration at either level. However, there was a slight decrease

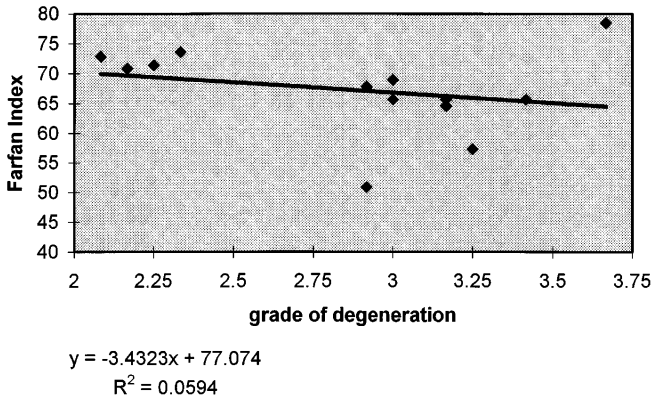

Fig. 5 Chart of Farfan index plotted against the degree of disc degeneration for L4/5 discs in subjects less than 40 years old

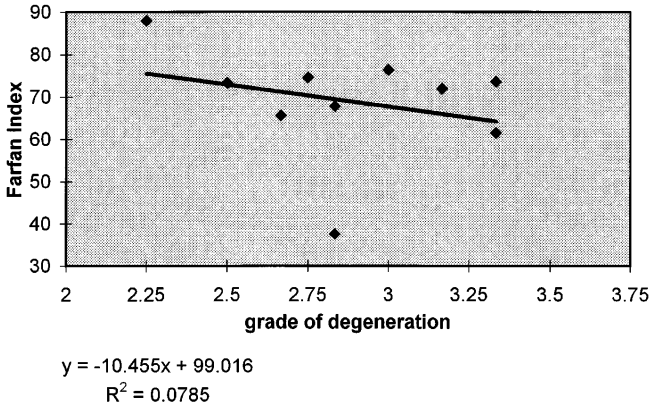

Fig. 6 Chart of Farfan index plotted against the degree of disc degeneration for L5/S1 discs in subjects less than 40 years old

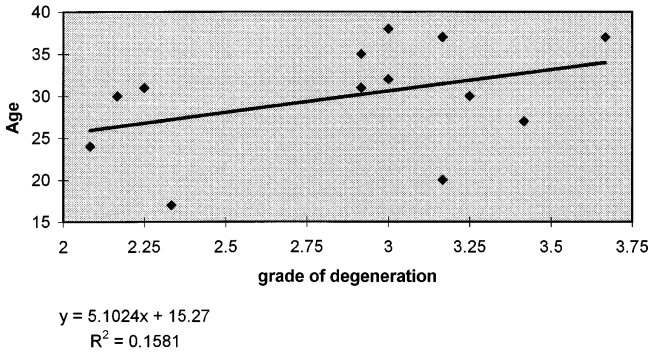

Fig. 7 Chart of L4/5 disc degeneration plotted against age in subjects less than 40 years old

of the Farfanindex with increasing degeneration at both levels (Figs. 5, 6). Disc degeneration tended to be more severe with increasing age at the L4/5 level (Fig. 7).

There was no correlation of disc degeneration with disc convexity either in the sagittal or the frontal plane.

Discussion

It has been stated that degeneration and aging of the disc inevitably results in intervertebral disc space narrowing [8, 24, 26]. This has important clinical significance, as pain might arise not only from the disc itself but also from increased pressure in the facet joints [10]. Other studies, however, have not confirmed a correlation between disc space narrowing and degeneration or aging [15]. In a series of 615 plain lateral radiographs of patients from different age groups, Amonoo-Kuofi [3] found that anterior as well as posterior disc height steadily increased until the fifth decade and declined thereafter. By exclusion of radiographs showing evidence of degenerative changes, these authors attempt to focus on the pure effect of aging on disc height. However, degenerative changes may not be apparent on plain radiographs, and ex vivo studies have demonstrated a rapid increase of degeneration with aging [14, 20]. Consequently, the impact of degeneration on disc height may be indistinguishable from the influence of aging [12].

Twomey and Taylor [22] compared radiographs of specimens from two age groups (20–35 years and over 60 years) and reported a clear trend of increasing disc height with aging. Due to osteoporotic changes, the vertebral endplate concavity became more pronounced with a consequent central expansion of the disc. The authors also state that the incidence of disc degeneration increases in the elderly, but they do not directly correlate degeneration grade and disc height.

Generally, radiological measurements from lateral radiographs of the lumbar spine may be affected considerably by variations in lateral tilt and longitudinal rotation of the spine. Additionally, interobserver variations influence the readings [4, 19]. Measurements according to Farfan's method [11] have been found to be the most accurate and repeatable [4, 9, 17, 21]. The index includes the anteroposterior disc diameter to correct for magnification, which is essential for comparison of discs of various sizes.

The present study also used Farfan's index, but all measurements were taken directly from the histological sections. In addition, measurements from three sagittal sections per disc were averaged for greater accuracy. Specimens of the L4/5 and L5/S1 level only were investigated, as degenerative changes occur most often and earlier in the two lowest motion segments [8]. Disc space narrowing with degeneration and aging is also most pronounced at these levels [23, 25].

Our data on posterior disc height are very similar to the data in the literature. However, values found for the anterior disc height of the lower lumbar segments are higher than those in the present study [16, 19]. The lower lumbar discs are positioned at the apex of the lumbosacral lordosis, which accounts for the wedge shape of the discs. Lumbar lordosis is more pronounced in vivo than in cadaver specimens, especially when lateral radiographs are taken with the patient standing [1]. This results in a more pronounced wedge shape of the disc, with a larger difference between anterior and posterior disc height [21].

Our results also showed a trend of increasing grade of disc degeneration at L4/5 with increasing age. However, there was only a weak decrease in the Farfan index with increasing disc degeneration. Changes in disc tissue structure and composition usually precede alterations in gross morphology [7]. It is conceivable that the alterations observed in this study with subjects less than 40 years of age were not sufficient to result in narrowing of the disc space. In this age group, the most likely cause for a permanent loss of tissue volume seems to be herniation of nucleus material into or even beyond the annulus fibres [6]. Herniation was, however, not observed in any of our cases. Severe changes of the annulus with disintegration

of laminar fibres may also contribute to a reduction in disc height, but these have only been found in individuals above the age of 40 years [5]. In consequence, pain arising from increased pressure in the facet joints due to a decrease of segmental height seems less likely in the younger age group.

A more pronounced disc convexity with age has been attributed to a "sinking" of the disc into the vertebral endplates with a decrease in bone density [23]. This phenomenon was not observed in our study, which may also be due to the relative youth of the cohort investigated. Similar disc investigations of elderly subjects should be undertaken to further analyse this effect of aging. The data of the present study confirm other observations that the convex shape is more pronounced at the L4/5 than L5/S1 disc [22]. However, at both levels, convexity was more pronounced in the frontal plane than the sagittal, illustrating a dome shape of the intervertebral disc.

Conclusion

Histological alterations in lower lumbar discs are observed in patients under the age of 40 years. They tend to become more pronounced with increasing age, specifically at the L4/5 level. However, the influence of these early changes on the disc height is minimal. It is hypothesized that the alterations are not sufficiently severe to cause an irreversible reduction in disc volume. We would therefore expect to find more significant disc height reduction in the elderly age groups with more advanced degenerative changes.

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