

Comparison of disc and body volumes in degenerated and nondegenerated lumbar discs: a stereological study

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Aim: To carry out comparison and correlation analyses of the intervertebral disc (IVD) and vertebral body (VB) volumes in magnetic resonance (MR) images of patients with degenerated and nondegenerated lumbar discs.

Materials and methods: MR images were examined retrospectively in 93 patients. Lumbar VB and IVD volumes in T1–T2 weighted sagittal MR images were calculated via the Cavalieri method, a stereological method. Volumetric changes in degenerated and nondegenerated discs were compared.

Results: The percentages of degenerated IVDs were 12.9%, 12.9%, 28%, 50.5%, and 52% in discs from levels L1 to L5, respectively. There were no differences in VB volumes between the degenerated and nondegenerated groups for all lumbar vertebra levels. However, significant volumetric decreases were observed in degenerated IVDs for all lumbar vertebra levels, as compared to nondegenerated IVDs. Comparisons of VB volume and IVD volume ratios also revealed decreases, but they were significant only for levels L1 and L4.

Conclusion: Disc volumes were found to be decreased, although vertebral bodies were not affected in degenerated IVD groups. However, using VB and IVD volume ratios may not always yield reliable results.

Key words: Degenerated intervertebral disc, lumbar vertebra, magnetic resonance imaging, stereology, volume

1. Introduction

The intervertebral disc (IVD) is the largest avascular structure in the human body. Nutrition of IVD cells is partly dependent upon IVD fluid, which flows out during the day and flows in during bed rest. The nutritional supply to IVD cells is said to be marginal, and long periods without adequate fluid exchange in the disc could be enough to initiate irreversible effects (1). In particular, increased axial load and abnormal postures may lead to loss of water in the IVD and lumbar back pain, which is one of the common complaints. The IVD also has complex structural and functional relationships. Therefore, it is constantly affected by several risk factors such as compression, bending, distraction, rotation, and the negative effects of a heavy workload (2,3). These influences lead to disc height-dimension variations and disc content changes, which consequently result in IVD volume changes (2,4).

Computed tomography (CT) and magnetic resonance imaging (MRI) are common procedures for obtaining

information about cranium, vertebral column, and spinal cord anatomy and pathologies (2,3,5). MRI can be highly sensitive for detecting degenerative changes and commonly displays pathologies that are not necessarily responsible for the patient's symptoms.

It is possible to estimate the volumes of structures such as the vertebral body (VB) and the IVD using a stereological method based on the Cavalieri principle. Results obtained through this approach are mathematically unbiased and free from any systematic error (2,6). The validity of this principle has been proven and applied in previous studies using different scanning techniques (2,6–10). This principle allows us to adopt a simple and inexpensive stereological approach that is suited to rapid and accurate volumetric estimation of normal and degenerative vertebral bodies (11).

The aim of this study was to carry out comparison and correlation analyses of IVD and VB volumes in patients referred to the clinic who had MR images showing degenerated and nondegenerated lumbar discs.

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2. Materials and methods

Retrospectively, lumbar MRI was examined in 93 patients with lower back pain. All of the patients underwent neurological examinations, after which MR images were examined. In MRI, degenerated IVDs were evaluated according to loss of signal intensity on T2W1, reductions in disc space height, annular tears, and modic changes. Patients with vertebral tumours, congenital abnormalities, infections, extruded/sequestered lumbar disc herniations that needed surgical intervention, instability (spondylolisthesis, trauma), or deformities (scoliosis) of the spine were excluded from the study.

MR images were examined with a 1.5-T device (Philips, Intera 1.5T) using the T1- and T2-weighted sagittal plane with 3-mm section imaging and T2-weighted transverse plane imaging. Volumetric estimates were performed in the sagittal plane images, which were printed on films in rectangular frames of 83 × 55 cm in length (Figure 1A).

Lumbar VB and IVD volumes were calculated from MRI slices using the Cavalieri principle, a stereological method, as described previously (2,5). A square grid system with $d = 2.5$ mm between test points, i.e. representing an area of 6.25 mm² per point, was used to estimate the surface areas of sagittal section plane slices. The films were then placed on a light box and each VB and IVD was identified with the guidance of a scanogram of the section series. The transparent square grid test system was randomly superimposed on the entire image frame (Figure 1B). Points hitting the surface area of the VB or IVD were manually counted for volume estimation using the following formula:

$$V = t \times [(SU \times d) / SL]^2 \times \Sigma P,$$

where t is the thickness of the section, SU is the scale unit (the real length of the scale marked on the MR images), d is the distance between 2 points in the point

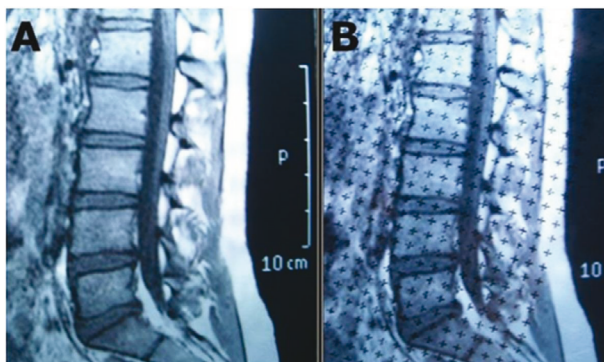


Figure 1. MRI scans of specimens without a point counting grid (A) and with a grid superimposed (B) on the sagittal plane MRI scan.

grid, SL is the scale length (the actual measure of the scale on MR images), and P is the number of points counted. All data were entered into a previously prepared Microsoft Excel spreadsheet for automatic calculation of both the results of the above formula and the statistical evaluation parameters, including the nugget variance and the coefficient of error (CE). Volumetric changes in degenerated and nondegenerated discs were compared.

2.1. Statistical analyses

Results are expressed as the number of observations (n) and the mean \pm standard deviation (SD). Distributions of the variables were analysed using the Shapiro–Wilk normality test. Parametric test assumptions were satisfied, and t -tests were applied to compare degenerated and nondegenerated disc VB and IVD volumes. Correlations among age and degeneration and VB and IVD volumes were performed using the Pearson correlation test. A P -value of less than 0.05 was considered as statistically significant. All statistical analyses were performed with SPSS 13.0 (SPSS Inc., Chicago, IL, USA).

3. Results

Thirty-two (34.4%) of the patients were male and 61 (65.6%) patients were female. Mean height was 165.56 ± 7.58 cm (range: 180–150 cm), and mean weight was 75.03 ± 14.69 kg (range: 48–145 kg).

The percentages of degenerated IVDs were 12.9% ($n = 12$), 12.9% ($n = 12$), 28% ($n = 26$), 50.5% ($n = 47$), and 52% ($n = 49$) for discs of levels L1–L5, respectively (Figure 2). Positive correlations were observed between age and IVD degeneration at levels L1 ($r = 0.239$, $P = 0.021$), L2 ($r = 0.285$, $P = 0.006$), L3 ($r = 0.574$, $P = 0.000$), L4 ($r = 0.362$, $P = 0.000$), and L5 ($r = 0.262$, $P = 0.011$). We found a strong correlation between level L3 and L4 IVDs.

All patients had low back pain but not neurological deficit. In neurological examination, Lasègue test of 80° and over was accepted as normal. Other patients suffering

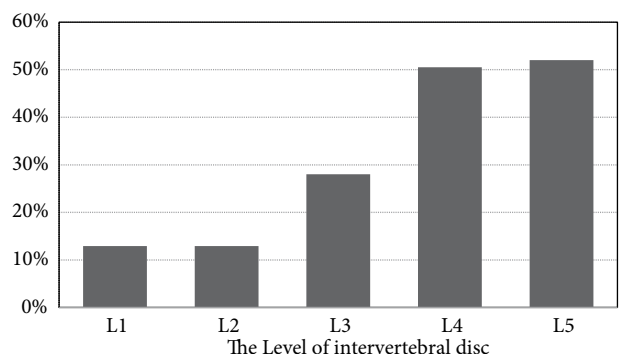


Figure 2. The percentages of degenerated intervertebral discs. The sum was 93.

from serious sciatica and neurological deficits related with sensorial and motor issues underwent surgical intervention and were excluded from the study.

VB and IVD volumes and VB/IVD ratios are shown in Figures 3–5 for degenerated and nondegenerated discs. There were no differences in VB volumes between degenerated and nondegenerated groups for all lumbar vertebra levels (Figure 3; Table 1). However, significant volumetric decreases were observed in degenerated IVDs for all lumbar vertebra levels as compared to nondegenerated IVDs (Figure 4; Table 2).

VB/IVD volume ratios were higher in the degenerated group. However, these increases were statistically significant only at the L1 (P = 0.000) and L4 (P = 0.019) levels. Furthermore, we observed during assessment of the nondegenerated group that VB/IVD volume ratios decreased from top to bottom, except at the L5/D5 level (Figure 5; Table 3).

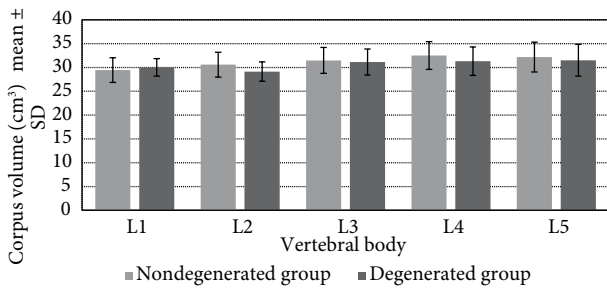


Figure 3. A comparison of lumbar vertebra volumes in degenerated and nondegenerated groups.

Table 1. A comparison of vertebral body volumes in the nondegenerated and degenerated disc groups. Data represent means ± SD (cm³); NS = nonsignificant (P > 0.05).

Corpus volumes (cm ³)	L1	L2	L3	L4	L5
Nondegenerated group	29.44 ± 2.59	30.58 ± 2.61	31.46 ± 2.72	32.51 ± 2.92	32.17 ± 3.13
Degenerated group	30.01 ± 1.84	29.13 ± 2.03	31.13 ± 2.73	31.33 ± 2.99	31.51 ± 3.33
P-values	NS	NS	NS	NS	NS

Table 2. A comparison of intervertebral disc volumes in the nondegenerated and degenerated disc groups. Data represent means ± SD (cm³).

Disc volumes (cm ³)	D1	L2	L3	L4	L5
Nondegenerated group	13.28 ± 0.93	14.50 ± 1.07	15.40 ± 1.32	16.53 ± 1.66	16.01 ± 1.42
Degenerated group	12.38 ± 0.70	13.61 ± 0.60	14.76 ± 1.18	15.05 ± 1.25	15.18 ± 1.35
P-values	0.002	0.006	0.035	0.000	0.005

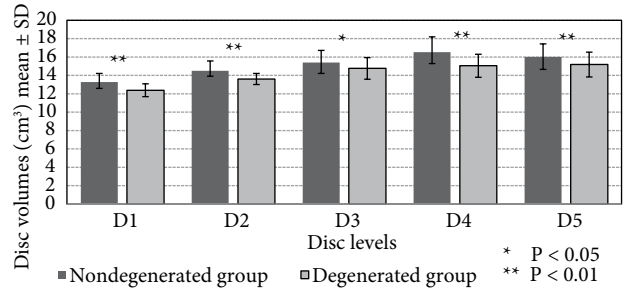


Figure 4. A comparison of lumbar intervertebral disc volumes in degenerated and nondegenerated groups.

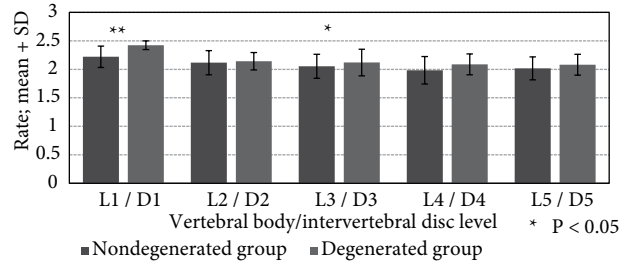


Figure 5. A comparison of the ratios of lumbar vertebral body volumes to intervertebral disc volumes in degenerated and nondegenerated groups.

4. Discussion

Stereological methods provide quantitative data on 3-dimensional structures using 2-dimensional images. By the Cavalieri principle, volume estimates of organs or structures use 2-dimensional scans of CT or MR images. It is not necessary to further standardise the CT or MRI

Table 3. A comparison of vertebral body volumes/disc volumes in the nondegenerated and degenerated disc groups. Data represent means \pm SD; NS = nonsignificant ($P > 0.05$).

Corpus/Disc	L1/D1	L2/D2	L3/D3	L4/D4	L5/D5
Nondegenerated group	2.222 \pm 0.188	2.117 \pm 0.213	2.054 \pm 0.210	1.983 \pm 0.241	2.017 \pm 0.202
Degenerated group	2.424 \pm 0.076	2.142 \pm 0.153	2.120 \pm 0.234	2.088 \pm 0.183	2.082 \pm 0.184
P-values	0.000	NS	NS	0.019	NS

scans in order to estimate the vertebral or IVD volumes. This method is inexpensive and rapid because point counting is carried out within a couple of minutes (2,6).

In our study, significant volumetric decreases were observed in degenerated IVDs for all lumbar vertebra levels as compared to nondegenerated IVDs. Nevertheless, concerning the lumbar VB volume comparison, there were no differences between degenerated and nondegenerated groups at all lumbar vertebra levels. Anatomical and morphological features of IVDs lead to changes in the composition of the IVDs (e.g., fluid loss, cell volume decreases, and diminished proteoglycan contents). Both changes in the composition of the IVDs and the load transfer on vertical axis to IVDs are possibilities related with the decrease in the volume of degenerated discs. The height and size of IVDs are commonly used to diagnose and evaluate pathologies of the spine. The degree of IVD degeneration has been commonly assessed by the decrease in disc height rather than by changes in signal intensity in the nucleus pulposus on MR images (2,3,12–15). Although disc height measurements provide an approximation of disc volume, this index may not always reflect actual volumetric values. For this reason, actual volumetric measurements are more informative with regard to IVD morphometry and injury. We performed stereological volume estimations of degenerated and nondegenerated vertebrae because such studies have not been performed previously.

Examination of VB/IVD volume ratios revealed that these ratios were increased in the degenerated group. However, these increases were statistically significant only at the L1/D1 and L4/D4 levels. In our study, the volumes of degenerated discs were decreased, except for L1 IVDs. However, these decreases were not statistically significant.

In our study, we observed that the percentage of degenerated IVDs was higher in the lower lumbar vertebral segments. We also found positive correlations between age and IVD degeneration. Kellgren and Lawrens reported similar findings in their study (16). Moreover, numerous studies have reported disc degeneration to be strongly correlated with obesity, race, sex, smoking, physical activity related to one's occupation and sports, vibration trauma, diabetes, aging, and genetic factors (17–22). The main

reasons for degeneration observed at the L4–L5 IVD level are thought to be high mobility, increased load, and stress (23–26). L1, L2, and L3 IVD herniations and degenerations are encountered in 1%–11% of the population. The most important causes are decreased activity and stress in the upper lumbar spine (27,28). In our study, we observed that the rates of IVD degeneration at levels L1–L3 were 12.9%, 12.9%, and 28%, respectively. Our findings are consistent with the literature, except for the L3 IVD values. The fact that the degeneration rate in L3 IVDs is high compared to literature values may be considered a distinguishing feature of our population.

Lower back pain is often due to disc degeneration, which is the most important cause of primary instability. Disc degeneration and consequent decreases in disc height, hypertrophy and widening of posterior facet joints, reductions in ligamentous tension, and increased mobility lead to degenerative segmental instability (29–31). Kirkaldy-Willis and Farfan defined the pathology of discogenic pain and degenerative instability and stated that minimal changes in segmental stability may cause major dysfunction (29). We believe the decrease in the volume of degenerated IVDs that we observed in our study may simply be due to a decrease in height. However, we consider it essential to make good estimations of the actual volume loss in disc degeneration using stereological methods.

Degenerative instability due to disc degeneration is mostly seen in L4–L5 discs. There are several reasons for this. Farfan et al. and Hopp and Tsou stated that ilio-transverse ligaments stabilise the L5, that additional stress is exerted on L4 IVDs, and that load transfer and disc degeneration occur mostly at the L4–L5 disc level (23,26). Frymoyer stated that the L4–L5 disc is the segment most prone to degeneration and degenerative instability (32). Allbrook showed that L4 discs have the highest degree of mobility, followed by L5 IVDs (24). He also demonstrated that because of the oblique placement of the facets between L4 and L5 vertebrae, they are susceptible to trauma. This may explain why degenerative spondylolisthesis is most frequently seen at the L4–L5 level (25). In our study, we found the highest rates of disc degeneration in L4 and L5 IVDs, at 50.5% and 52%, respectively.

In conclusion, the degree of lumbar disc degeneration increases at lower vertebra levels. This may be due to the increased load and stress and the higher range of mobility in lower vertebrae. This volumetric study supports the knowledge that degenerated lumbar discs could have

a decreased height and are situated frequently at lower lumbar disc levels. It also suggests that vertebral body volumes are not affected by the changes of intervertebral disc volume. However, using the disc volume/body volume ratio may not always yield reliable results.

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