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Height of lumbar discs measured from radiographs compared with degeneration and height classified from MR images

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Abstract The relation between height of lumbar discs (measured from lateral radiographic views) and disc degeneration (classified from MR images) deserves attention in view of the wide, often parallel or interchanged use of both methods. The time sequence of degenerative signs and decrease of disc height is controversial. To clarify the issue, this cross-sectional study documents the relation between disc degeneration and disc height in a selected cohort. Forty-three subjects were selected at random from a cohort examined for potential disc-related disease caused by long-term lifting and carrying. From each subject a lateral radiographic view of the lumbar spine as well as findings from an MR investigation of (in most cases) levels T12/L1 to L5/S1 were available; thus, $n = 237$ lumbar discs were available for measurement and classification. Disc height was measured from the radiographic views with a new protocol compensating for image distortion and permitting comparison with normal, age- and gender-appropriate disc height. Degeneration as well as disc height were classified twice from MR images by independent observers in a blinded fashion. Disc degeneration classified from MR images is not related to a measurable disc height loss in the first stage of degeneration, whereas progressive degeneration goes along with progressive loss of disc height, though with considerable interindividual variation. Loss of disc height classified from MR images is on average compatible with loss of disc height measured from radiographs. In individual discs, however, classification of height loss from MR images is imprecise. The first sign of disc degeneration (a moderate loss of nucleus signal) precedes disc height decrease. As degeneration progresses, disc height decreases. Disc height decrease and progress of degeneration, however, appear to be only loosely correlated.

Key words Lumbar discs · Disc height measurement · Disc degeneration

Introduction

Degenerative disc disease has a close relationship to the reduction of disc height as Twomey and Taylor [1] showed in a cadaver study. Detection of alterations of lumbar disc tissue composition employing MR imaging and assessment of height loss of lumbar discs from radiographs are often performed in parallel or in an interchangeable fashion when documenting severity or progression of lumbar disc disease. Although there is general agreement that severe disc degeneration goes along with a noticeable loss of disc height, the time sequence between tissue changes detected by the loss of signal in T2-weighted MR images, on one hand, and

Table 1 Definition of degeneration categories A–L derived from inspection of MR images

	Nucleus signal	Prolapse detection	Bone marrow signal
A	No signal loss	No prolapse	No intensity change
B	No signal loss	Prolapse	No intensity change
C	No signal loss	No prolapse	Intensity change
D	No signal loss	Prolapse	Intensity change
E	Moderate signal loss	No prolapse	No intensity change
F	Moderate signal loss	Prolapse	No intensity change
G	Moderate signal loss	No prolapse	Intensity change
H	Moderate signal loss	Prolapse	Intensity change
I	Total signal loss	No prolapse	No intensity change
J	Total signal loss	Prolapse	No intensity change
K	Total signal loss	No prolapse	Intensity change
L	Total signal loss	Prolapse	Intensity change

height loss of lumbar discs estimated from MR images or radiographs, on the other, has not been fully resolved.

In the past, the inability to establish the relationship between degeneration of disc tissue and the height loss of discs was partially due to the fact that conventional procedures to measure disc height from lateral radiographs or to estimate disc height from MR images were prone to inaccuracies due to image interpretation and, in the case of radiographs, due to image distortion caused by central projection. Recently, however, a new protocol for precise measurement of disc height from lateral radiographs of the lumbar spine has been proposed and validated [2]. Employing this protocol, disc height can be measured with an error of approximately 4 % and compared with age- and gender-appropriate normal values.

The availability of data from an MR investigation as well as radiographs of the complete lumbar spine of a cohort examined for potential work-related disc disease offered a unique possibility to re-investigate the relation between degeneration and height loss of lumbar discs. As a by-product, the precision when grading loss of disc height from MR images could be assessed by comparison with a measurement of disc height from radiographs when using the new protocol.

Methods

Cohort investigated

Forty-three subjects (15 men and 28 women; mean age 41 years) were selected at random from a cohort of construction workers and hospital nursing staff examined for potential work-related disc disease caused by long-term (i.e., more than 10 years) exposure to lifting and carrying. From each subject a lateral radiographic view of the lumbar spine as well as findings from an MR investigation covering (in most cases) levels T12/L1 to L5/S1 were available. This amounted to 237 lumbar discs available for measurement and classification. With few exceptions, all lumbar spines demonstrated signs of disc degeneration and decrease of disc height in at least one lumbar disc hypothetically caused by primary mechanical overloading.

Classification of disc height and disc degeneration by MR

Magnetic resonance images were taken using a Siemens Magnetom Vision at 1.5 T. The operational modes employed were T1-weighted spin-echo sequences (TR 500 ms, TE 20 ms) and T2-weighted spin-echo sequences (TR 3200 ms, TE 160 ms). Following the outline of Modic et al. [3, 4] and Ito et al. [5] three items related to disc degeneration were assessed:

1. Nucleus signal, classified from the T2-weighted image as 1 (no signal loss), 2 (moderate loss) or 3 (total loss)
2. Prolapse, classified from the T1-weighted image as 1 (no prolapse) or 2 (prolapse)
3. Bone marrow signal of adjacent vertebral body, classified from the T1- and T2-weighted image as 1 (no intensity change) or 2 (intensity change)

In combination, the classification resulted in $3 \times 2 \times 2 = 12$ degeneration categories ranging from A to L (Table 1). Each disc was unambiguously related to one (and only one) of these 12 categories. In addition, disc height was classified from MR images into four classes as 0 (normal), 1 (moderate loss, i.e., < 50 % with respect to adjacent disc), 2 (50 % loss) or 3 (severe loss, i.e., more than 50 %).

Measurement of disc height from lateral radiographic views

Measurement of disc height from lateral radiographic views of the lumbar spine followed a new protocol, designed to compensate for previously identified factors of imprecision such as distortion in central projection, off-center position, axial rotation, and lateral tilt of the spine. Herein this new protocol is referred to as distortion-compensated roentgen analysis (DCRA). Distortion-compensated roentgen analysis, a further development of Farfan's proposal for measuring disc height, is briefly reiterated herein (for details, the reader is referred to [2]).

Figure 1 shows a lumbar vertebra and those vertebral body contours which can be identified in the lateral radiographic image. Landmarks, termed ventral and dorsal corners, are defined as contour points of maximum distance from reference points within the vertebral silhouette by a computerized algorithm. In many radiographs, the full set of four dorsal corners is not visible due to overlay from other structures or to deficient film quality. But those two dorsal corners (1 and 3) which are positioned on the outermost contours and the two ventral corners (2 and 4) can always be distinguished; thus, measurement of disc height employing DCRA is based exclusively on corners 1–4 of adjacent vertebrae.

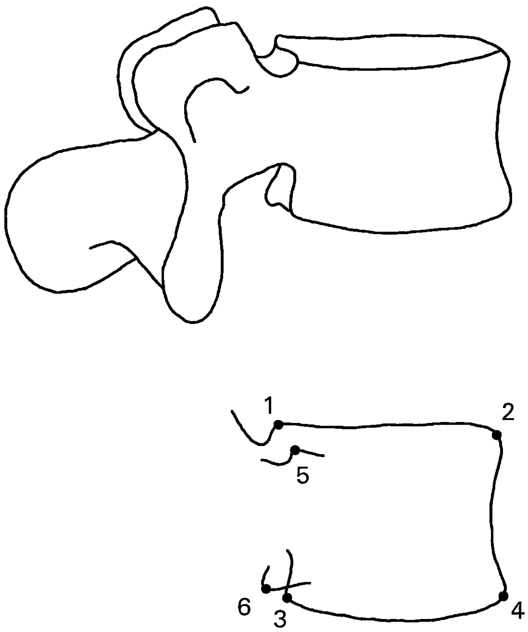

Fig. 1 Sketch of a lumbar vertebra, viewed obliquely from above and rotated axially a few degrees to the left. Vertebral contours can be identified in a lateral radiographic view. Corners are computed as points of maximum distance from reference points located within the silhouette of the vertebral body. There are two ventral (*2*, *4*) and four dorsal corners (*1*, *3*, *5*, *6*). Definition of disc height is based only on corners *1–4*. (From [2])

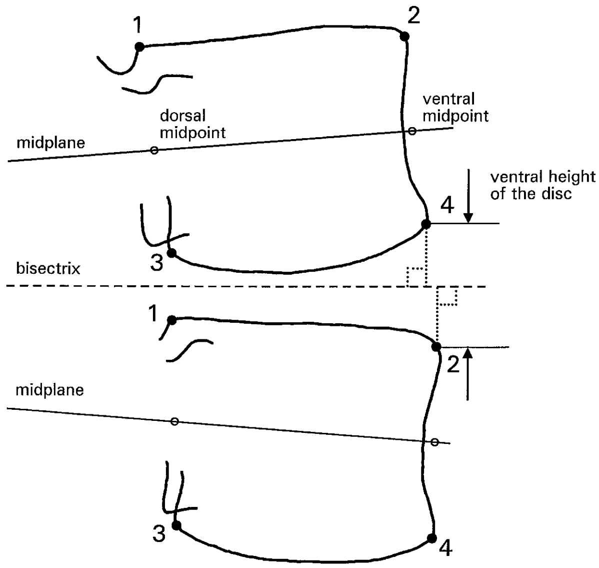

Fig. 2 New protocol for measuring height of lumbar discs (motion segment imaged in a projection similar to that of Fig. 1). Ventral and dorsal midpoints, midplanes, and their bisectrix are constructed. The ventral height of the disc is determined by the sum of the distances of corner *4* of the cranial vertebra and corner *2* of the caudal vertebra from the bisectrix. To compensate for variations in stature and magnification, ventral disc height is divided by the mean depth (mean of cranial and caudal depth) of the cranial vertebra. A correction converts the measured height to disc height at a standard angle of lordosis. Angle standardization permits comparison of disc height from radiographs taken in different postures

Ventral and dorsal midpoints are defined as midpoints between corners 2 and 4 and corners 1 and 3 (Fig. 2). The line connecting the ventral and dorsal midpoints is termed midplane. The sagittal plane angle between two adjacent vertebrae is given by the angle between their midplanes. The ventral height of a lumbar disc is defined as the sum of the perpendicular distances of corner 4 of the cranial vertebra and corner 2 of the caudal vertebra from the bisectrix between the two midplanes. To compensate for radiographic magnification and variation of stature, ventral disc height is divided by the mean depth of the cranial vertebral body. This quotient is a dimensionless number; in healthy subjects, mean values of this quotient range (depending on anatomic level, gender, and age) between 0.23 and 0.42.

Ventral disc height depends on the angle of lordosis. To compare disc height data from radiographs taken in different postures, a correction is applied converting disc height measured at arbitrary angles to height at standard angles. For this purpose, the magnitude of the physiologic change of disc height with sagittal plane angle was determined by linear regression analysis from lateral lumbar radiographs of healthy subjects. The regression coefficients, determined separately for all lumbar levels and both genders, are employed in a correction equation. The resulting angle-standardized disc height is independent of patient posture.

The relative location of ventral vertebral corners as well as of ventral and dorsal midpoints is virtually uninfluenced by distortion in central projection. This also holds true for the angle between the midplanes. Consequently, the measurement of disc height following the new protocol is virtually uninfluenced with respect to axial rotation, lateral tilt, and off-center positioning. Height of all lumbar discs (T12/L1 to L5/S1) imaged on a lateral radiographic view can be measured. Special control of patient alignment with respect to the radiographic film and tube is not required; normal positioning is sufficient. Geometry of the X-ray apparatus need not be known; thus, retrospective studies are feasible.

The technical procedure to measure disc height from lateral radiographic views comprises identification of the vertebral contours, mapping of the contours onto a transparent foil and digitization of the contour lines (point density 5 per mm, precision 0.125 mm). Series of programs check geometric properties of the contours, locate corners, calculate derived geometric measures and compute angle-standardized disc height.

A database documenting biological variation and age dependence of disc height in the range between skeletal maturity and 57 years has previously been compiled from 892 lateral radiographic views of healthy male and female subjects [2]. This permits comparison of measured height of an individual disc with its level-, gender- and age-appropriate normal height value.

Error study

To assess errors when classifying disc degeneration as well as disc height from MR images into classes from A to L or zero to 3, respectively, all discs on all MR images were classified by two observers in a blinded fashion.

Errors of disc height measurement by DCRA have been assessed in previous studies [2]. Angle-standardized disc height is measured by DCRA from lateral radiographic views with a rela-

Table 2 Classification of disc degeneration from inspection of MR images into categories A–L by observers 1 (rows) and 2 (columns). For definition of categories see Table 1. Categories B, C, D, and H are omitted from this table because there were no entries by either observer

	A	E	F	G	I	J	K	L	Σ
A	127	0	0	0	0	0	0	0	127
E	0	22	0	0	0	0	0	0	22
F	0	0	1	0	0	0	0	0	1
G	0	0	0	1	0	0	0	0	1
I	0	3	0	0	30	0	0	0	33
J	0	2	1	0	5	20	0	0	28
K	0	0	0	0	0	0	3	0	3
L	0	0	0	0	0	0	1	21	22
Σ	127	27	2	1	35	20	4	21	237

Table 3 Classification of disc height from inspection of MR images into classes 0–3 by observers 1 (rows) and 2 (columns). Class 0 designates normal disc height and class 3 designates maximally decreased disc height

	0	1	2	3	Σ
0	170	3	1	0	174
1	8	21	0	0	29
2	1	3	18	0	22
3	0	0	2	10	12
Σ	179	27	21	10	237

tive error of 4.15%. Inter- and intra-observer error of disc height measurement was shown to be lower than 0.005 (in units of the mean vertebral depth of the cranially adjoining vertebral body).

Statistical tools

In this study, the height of each disc is quoted not by its absolute height value but by its deviation from the gender-, age- and level-appropriate normal value derived from the aforementioned database. Quoting disc height as a deviation from normal in units of the standard deviation (and not in absolute numbers) allows disc height data from anatomical levels T12/L1 to L5/S1 to be pooled. For this purpose, the age- and angle-corrected disc height y is transformed into the variable u

$$u = (y-Y)/s,$$

with Y and s designating the mean and standard deviation of the norm population. For example, a height of $u = -1$ indicates that the height of the disc in question is one standard deviation lower than normal. For the norm population, the mean of the variable u equals zero and its standard deviation equals approximately one.

Statistical difference of cohort means of standardized disc height u with respect to the normal database was assessed by the two-tailed *t*-test. The level of significance for two-tailed testing was set to 0.05. The agreement of the two observers when classifying disc height and disc degeneration from MR images was characterized by the kappa index [6].

Results

The results of observers 1 and 2 when classifying disc degeneration or disc height from MR images are summarized in contingency tables (Tables 2, 3). In general, the two observers showed surprisingly good agreement. With respect to degeneration (Table 2), the only obvious discrepancies occurred when assigning degeneration categories E and J. When classifying degeneration, the kappa index amounted to 0.924. In the case of disc height (Table 3), the kappa index amounted to 0.820. Due to the excellent agreement between observers 1 and 2, the figures illustrating the relation between MR findings and DCRA disc height measurement show only results from observer 1, as results from observer 2 were virtually identical.

The relation between disc degeneration classified by MR and disc height measured by DCRA is compiled in Table 4. While mean disc height in degeneration categories A and E is virtually identical and does not significantly differ from normal, mean disc height decreases when going from category E to category L. Disc height in categories I, J, and L deviates significantly from normal. For category K there is a tendency to deviate from normal; however, significance could not be established as only a few discs fell into this category. In each degeneration category disc height exhibits considerable variation. For example, discs classified as category I (complete loss of the nucleus signal but no prolapse or bone marrow intensity change) deviate on average by $u = -1.231$ from normal but vary in height between $u = -4.227$ and $u = +1.120$. Figure 3 illustrates the distribution of disc height measured by DCRA in relation to the MR degeneration categories.

The relation between disc height classified from MR images and disc height measured by DCRA is compiled in Table 5. Mean disc height measured by DCRA decreases monotonously from class zero to class 3 as classified from MR images. Discs classified as class zero, i.e., judged to exhibit normal height from inspection of the MR image, show on average only a very small devi-

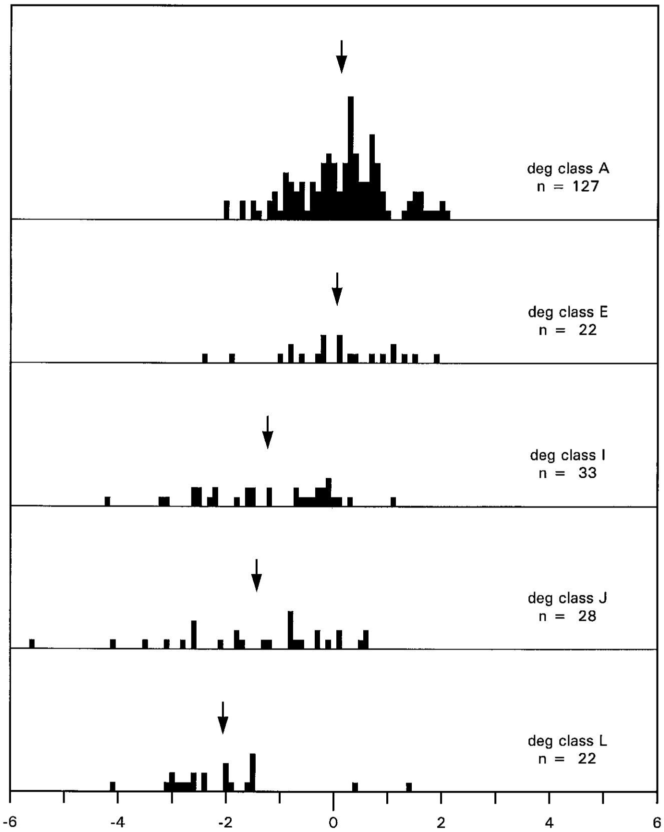

Fig. 3 Disc degeneration classified from MR images (data of observer 1) in relation to disc height measured by distortion compensated roentgen analysis (DCRA) from radiographs. The DCRA-measured disc height is expressed as a standardized deviation from normal age- and gender-appropriate height. Mean height in each degeneration class is indicated by *arrows*. Only degeneration classes with at least 22 entries are shown

ation from normal height. There is, however, a wide variation of height within this class. Discs actually deviating in height by more than u = –2 from normal had still been classified as having normal height. Discs classified as classes 1–3, i.e., judged to exhibit decreased disc height, show on average a decrease in height; however, within each class there is again considerable scatter. For example, discs in class 2 deviate from normal in height between u = –5.554 and u = + 0.398. Figure 4 illustrates the distribution of disc height measured by DCRA in the four disc height classes derived from inspection of the MR images.

Discussion

The results of this study show that first signs of disc degeneration (classified from MR images) and loss of disc height (measured by DCRA) are not observed simultaneously. Discs in degeneration categories A (no findings) and E (moderate nucleus signal loss) show on average no deviation in height from normal. It is concluded that the process of disc degeneration precedes the process of loss of disc height. Only when disc degeneration proceeds, as indicated by a total loss of the nucleus signal and additional findings, such as prolapse or bone marrow intensity change (degeneration categories I to L), is the average value of disc height seen to decrease; however, discs in each degeneration category exhibit a considerable variation in height. This supports the inference that in the individual case the status of disc degeneration and the absolute value of disc height are only loosely correlated. It also complies with the findings of Hartwig et al. [7] who found no radiological degenerative changes in all cases of degenerative signs in the MRI.

These results do not comply with the findings of Berlemann et al. [8] who investigated the relation between degeneration and disc height in specimens.

Table 4 Disc height measured by distortion compensated roentgen analysis (DCRA) in relation to disc degeneration from MR images (MR data from observer 1, degeneration categories B, C, D, and H omitted because there were no entries). For definition of degeneration categories see Table 1. The DCRA-measured disc height is stated as a standardized deviation from normal age- and gender-appropriate height. In addition to the mean value of disc height, the SD as well as minimum and maximum height values are listed. Data from discs T12/L1 to L5/S1 are pooled; *n* number of discs measured and classified

MR degeneration category	DCRA mean height	*n*	SD	Min	Max	Significance
A	+ 0.131	127	0.872	–2.045	+ 2.149	n.s.
E	+ 0.055	22	1.019	–2.383	+ 1.884	n.s.
F	+ 0.261	1	–	–	–	–
G	–1.263	1	–	–	–	–
I	–1.231	33	1.228	–4.227	+ 1.120	**
J	–1.430	28	1.508	–5.553	+ 0.644	**
K	–2.760	3	1.742	–4.467	–0.984	n.s.
L	–2.052	22	1.171	–4.123	+ 1.351	**

Level of significance 0.05; n.s. $p > 0.05$; $^{**}p < 0.0001$

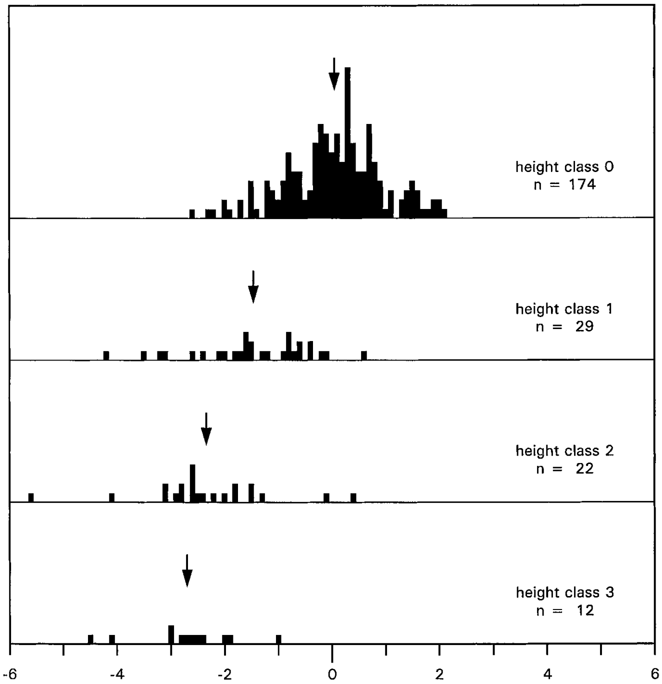

Fig. 4 Disc height classified from MR images (data of observer 1) in relation to disc height measured by DCRA from radiographs. The DCRA-measured disc height is expressed as a standardized deviation from normal age- and gender-appropriate height. Mean height in each height class is indicated by *arrows*

Grading disc degeneration based on previous descriptive studies and measuring disc height by the Farfan index, these authors found no significant correlation between the Farfan index and the extent of disc degeneration. The disagreement may be due to the fact that degeneration classification derived from inspection of tissue histology and classification of degeneration from MR images might not yield identical results. More importantly, the disc height of specimens may have been changed in an uncontrolled fashion with respect to the in vivo values due to the unloaded state of the specimens.

The comparison of disc height graded from inspection of MR images with disc height measured from radiographs employing DCRA showed that average disc height decreased continuously when going from MR height class 0 (no height loss) to height class 3 (maximal height loss). In each height class, however, a large scatter of disc height is observed, indicating considerable imprecision when qualitatively classifying individual disc height from MR images. This imprecision may be due to the fact that, within each MR image, the observer classifies disc height primarily with respect to the height of neighboring discs and not with respect to an age- and gender-appropriate normal height; thus, for example, if all discs on an image actually tend to be lower than normal, these discs are likely to be classified as normal, whereas the DCRA measurement unequivocally documents their deviation from normal. Classification of disc height from MR images may also be influenced by the presence of degenerative changes because the borderline between disc space and vertebral bone might be obscured. In addition, small postural changes may confound classification of disc height because a low angle of lordosis results in a decrease of ventral height of a disc. This decrease might then suggest a general decrease of height. The DCRA measurement, in contrast, relies on the bony vertebral contours and corrects for postural changes.

Classification of disc degeneration from inspection of MR images into 12 categories was chosen for scientific purposes to assign each disc unambiguously to one (and only one) of these categories. Whereas category A contains normal discs with no findings, category L contains discs in the state of maximal degeneration. From the number of entries in each category, conclusions on the time sequence of the signs indicating degeneration can be drawn. Absence of entries in categories B, C, and D indicates that prolapse or bone marrow intensity change do not occur in discs showing a normal nucleus signal. In other words, loss of nucleus signal is the first sign of the degeneration process. Prolapse and bone marrow intensity change are still rare in discs with moderate loss of the nucleus signal (categories E, F, G, H). Only discs

Table 5 Disc height, measured by DCRA, in relation to disc height classified from inspection of MR images (data of observer 1). The MR classes range from 0 (normal disc height) to 3 (maximally decreased disc height). The DCRA measured disc height is expressed as a standardized deviation from normal age- and gender-appropriate height. In addition to the mean value of disc height, its SD as well as minimum and maximum height values are listed. Data from discs T12/L1 to L5/S1 are pooled; *n* number of discs measured and classified

MR height class	DCRA mean height	*n*	SD	Min	Max	Significance
0	+ 0.051	174	0.915	–2.558	+ 2.149	n.s.
1	–1.460	29	1.115	–4.227	+ 0.644	**
2	–2.338	22	1.219	–5.554	+ 0.398	**
3	–2.697	12	0.938	–4.467	–0.984	**

Level of significance 0.05; n.s. $p > 0.05$; $^{**}p < 0.00001$

with a total loss of nuclear signal exhibit prolapse or bone marrow intensity change (or both). It has to be pointed out that these conclusions are tentative due to the low prevalence of disc prolapse or bone marrow changes even in this selected cohort.

In conclusion, a comparison of lumbar disc degeneration (classified from MR images) and disc height loss (measured from radiographs employing a new, precise protocol) is presented for the first time. The first stage of disc degeneration, indicated by a moderate loss of the nucleus signal, is not correlated with a loss of disc height. Only as degeneration progresses is increasing loss of disc height seen. In the individual case, however, loss of disc height and state of degeneration appear to be only loosely correlated. Whereas classification of disc height from MR images is on average compatible with precise measurement of disc height from radiographs employing DCRA, classification of disc height from MR images in the individual case is performed only with a considerable error.

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