Magnetic resonance imaging of normal lumbar intervertebral discs

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ABSTRACT

Objective: To study changes in midpoint lumbar disc heights in an asymptomatic Jordanian sample relative to age, sex, lumbar level and midvertebral heights.

Methods: A total of 153 asymptomatic patients (87 males, age range 20-65 years; mean 43+/-12.1 and 66 females, age range 22-68 years; mean 47+/-13.7) were selected during the study period. All underwent midsagittal magnetic resonance imaging to measure the midpoint disc height and midvertebral height of all lumbar spines. Values were statistically analyzed to obtain the significance of differences in the means of midpoint disc heights at different levels in every age group and among other age groups. The relative height indices for every lumbar level in each age group for both males and females were determined.

Results: The results showed that a highly significant sex-independent cephalocaudal increase sequence of midpoint disc heights is evident, where maximum values are reached at lumbar 3/4 level in the younger age groups and at lumbar 5/sacral 1 level in older ones. In relation to age, midpoint disc heights displayed a non-linear, alternating increase/decrease pattern, which was of higher magnitude and statistically significant in males, but less evident and statistically insignificant in females. Maximum values were reached during the 6th decade in males while during the 5th decade in females. The relative height indices were similar in both sexes and remained fairly constant between age groups at all levels.

Conclusion: The craniocaudal and age-dependent patterns could be termed physiological and interpreted as adaptation of the lumbar spine to changing functional demands. The utility of the relative height index is discussed.

Keywords: Magnetic resonance imaging, midpoint disc height, relative height index, normal intervertebral disc.

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The spine possesses a considerable degree of flexibility, which is primarily attributable to the presence of intervertebral discs.[1] The nature of this flexibility is directly related to the structural and biochemical characteristics of both the annulus fibrosus and nucleus pulposus.[1,2] In this regard, the relative size of the nucleus pulposus, and its capacity to swell with water make it able to act rather as a water-filled cushion, which is well suited for equal distribution of pressure in a manner essentially independent of the position of vertebrae to each other.[3] Moreover, the oblique criss-crossing arrangement and the unequal distribution of fibers of the annulus fibrosus allow the latter to withstand high bending and torsion.[3,4] From a clinical point of view, low back pain and disc herniation represent a major health problem and are influenced by multiple factors including age and gender.[5,6] Indeed, low back pain ranks high as the most common and most expensive health problem.[7] About 80% of Americans suffer from low back pain, men as often as women.[8] Approximately 10% of all low back pain cases were attributed to changes of the intervertebral discs.[7] As to the pathohistological and

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pathophysiological aspects, evidence brought by Naylor[9] showed that the intervertebral discs undergo an age-related process of degeneration as early as the 2nd decade, which is manifested by gradual structural transition of the disc components. The period during which the nucleus pulposus undergoes transition from a watery gel to a fibrous solid, reaching a peak on the 4th decade, actually coincides with the onset of disc herniation namely, between the 3rd and 5th decades.[10] Gower and Pedrini,[11] studied the structural and biochemical changes in aging discs and reached the conclusion that disc degeneration could represent a normal aging process, which, as described by other authors[3,12] could be explained as an adaptation process of the discs to the mechanical demands put upon them. As the biochemical properties of the discs change, the architecture of the discs becomes altered in the form of decreased height and subsequent narrowing of the disc space. This eventually renders the individual discs to behave as solid bodies, thus adding to low back pain.[3] In Jordan, an increasing number of patients seek professional help from neurosurgeons and orthopedists for problems related to low back pain. Unfortunately, quantitative studies concerning the lumbar spine in Jordanians in health and disease are, to our best knowledge, still absent. The present study is aimed at the morphometric evaluation of lumbar intervertebral discs using Magnetic Resonance Imaging (MRI) in a selected sample of asymptomatic Jordanian individuals. Special reference is made to changes in disc heights relative to age, gender and lumbar level, and to changes in vertebral heights. The established database would eventually serve as a reference in the evaluation of lumbar discs in symptomatic patients.

Methods. ***Patients.*** A hospital-based study was conducted between June 30, 1999 and June 30, 2000 by selecting 153 patients: 87 Males (age range 20-65 years; mean 43 +/- 12.1 years) and 66 females (age range 22-68 years, mean 47+/-13.7 years). Criteria for selection included patients who were referred to the MRI unit in Jordan University Hospital for abdominopelvic problems with no history of back ailment and showed normal lumbar spine signal intensity. The patients were divided into 5 age groups (decades). The details of group distribution are included in (Table 1).

Technique. The lumbar spines were examined with a Magnetom Vision Plus MRI Unit with a 1.5-Tesla magnet (Siemens, Erlangen, Germany). T1-weighted images in the sagittal plane were obtained using a single spin-echo technique with a repetition time (TR) of 500-millisecond, echo time (TE) of 15-millisecond with 3 acquisitions and 2 saturations. Slice thickness was 3mm, field of view 30cm, imaging area T12-S1. Twelve sagittal images scanning from right to left were performed for each patient in the supine position. The images were obtained using a spine array coil. The axial images (5-slices) were parallel to the axial plane of the intervertebral disc. Obtained images were reconstructed on 512 x 512 matrix and displayed on the Sun Ultra-Sparc computer system in a 1024 x 1024 matrix.

Table 1 - Means and standard deviations for midpoint disc heights (Dh) with age and sex.

Level	**Age Groups (Years)**					**ANOVA**
	20-29.9	**30-39.9**	**40-49.9**	**50-59.9**	**60-69.9**	**p-value**
L1/2	M 8.5 ± 0.9 n = 12 F 9.5 ± 0.5 n = 6	M 10.1 ± 1.5 n = 21 F 10.5 ± 2.9 n = 15	M 9.8 ± 1.3 n = 30 F 10.3 ± 1.9 n = 18	M 10 ± 1.2 n = 12 F 9.8 ± 1.1 n = 12	M 8.8 ± 1.5 n = 12 F 9 ± 1.6 n = 15	M 0.003 F 0.150
L2/3	M 9.8 ± 1.1 F 11 ± 0	M 11.3 ± 1.7 F 10.8 ± 1.5	M 10.7 ± 11 F 11.8 ± 1.8	M 11.8 ± 1.6 F 11.8± 1.1	M 11.5 ± 1.5 F 10.4 ± 2	M 0.008 F 0.065
L3/4	M 11.3 ± 1.1 F 12 ± 1	M 13.1 ± 1.2 F 12.6 ± 1.2	M 12.4 ± 1.3 F 12.8 ± 2.1	M 13.3 ± 0.8 F 12.2 ± 0.4	M 10.8 ± 3 F 11.8 ± 2.4	M 0.0001 F 0.5200
L4/5	M 11.5 ± 2.1 F 12 ± 0	M 11.4 ± 1.1 F 12.6 ± 1.0	M 12.1 ± 1.9 F 12.7 ± 3.2	M 13.8 ± 1.9 F 11.7 ± 0.8	M 11.8 ± 4.6 F 11.6 ± 1.6	M 0.174 F 0.065
L5/S1	M 9 ± 2.1 F 11.5 ± 0.5	M 12.1 ± 2.8 F 12 ± 1.5	M 12.7 ± 2.1 F 11.2 ± 3	M 12 ± 2.6 F 12.5 ± 1.8	M 13.3 ± 4.7 F 13.2 ± 2.9	M 0.003 F 0.187
ANOVA	M 0.000	M 0.000	M 0.000	M 0.000	M 0.044	
P-Value	F 0.000	F 0.000	F 0.044	F 0.000	F 0.000	

M - males; F - females; n - number of patients in each age group.

Figure 1 - Sagittal magnetic resonance image of the lumbar spine, demonstrates positions of markers for measuring the midpoint vertebral height (L_3). AB - superior endplate; CD - inferior endplate; S_1 - Midpoint of AB; i_1 - midpoint of CD; S_1-i_1 - midvertebral height in mm marked (3 = 28 mm) by computer.

Figure 2 - Sagittal magnetic resonance image of the lumbar spine, demonstrates positions of markers for measuring the intervertebral disc between L_3/L_4. AB - superior endplate of lower adjacent vertebra (L_4); CD - inferior endplate of upper adjacent vertebra (L_3); S_2- Midpoint of AB; i_2 - midpoint of CD; S_2-i_2- midpoint disc height in mm marked (3 = 16 mm) by computer.

Measurements. In this study the anterior and posterior limits of the superior (A-B) and inferior (C-D) vertebral endplates were marked. The line joining the midpoints of the superior (s_1) and inferior (i_1) endplates of each vertebra is considered as the midpoint height (s_1-i_1) for that particular vertebra (Vh) (Figure 1). The midpoint disc heights are obtained by the line joining the midpoints of the vertebral endplates of the 2 adjacent vertebrae (i_2-s_2) related to that particular disc (Dh) (Figure 2).

Statistical analysis. The means and standard deviations of midpoint disc heights (Dh, SD) and means of midpoint vertebral heights (Vh) were recorded and calculated to the nearest 0.1mm for every lumbar level in males and females in each age group. The relative disc height index (I), which is adopted as a measure of comparison of changes of disc heights in relation to changes of vertebral heights[13] was calculated for each lumbar level in all age groups for both males and females where $I = \bar{x}Dh/\bar{x}Vh$. The statistical significance of differences in disc heights between age groups at every lumbar level and between different levels in every age group in males and females was calculated using analysis of variance (ANOVA) and paired t-test at 0.05 level of significance. All data was analyzed by using an IBM compatible PC.

Results. ***Midpoint disc heights.*** The midpoint disc heights for males and females (for every lumbar level and in all 5 age groups) are given in (Table 1 and Figure 3 and 4).

Cephalocaudal changes. An obvious highly significant sex-independent cephalocaudal sequence is evident. Taking the values of L1/L2 as reference,

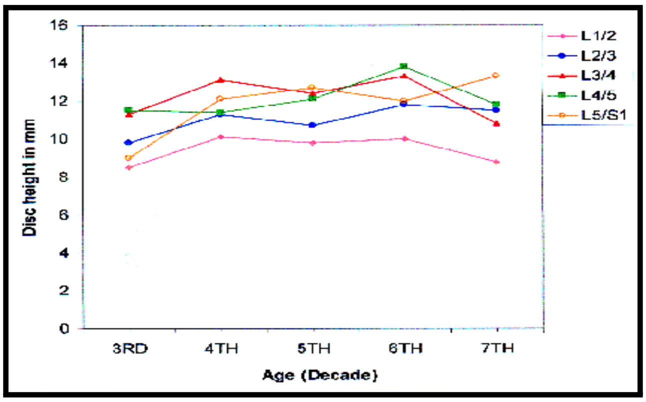

Figure 3 - Disc heights in males by age.

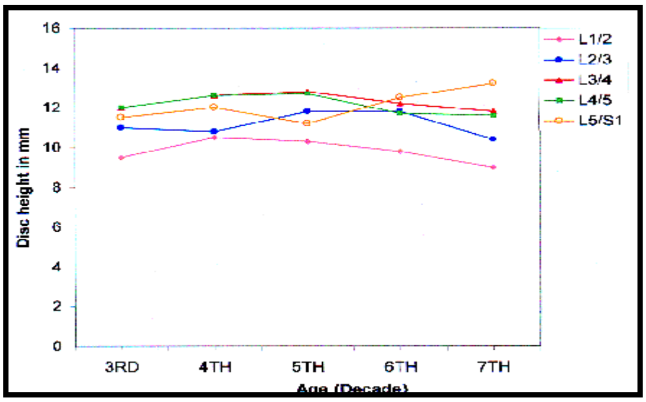

Figure 4 - Disc heights in females by age.

Table 2 - Relative disc height (I) index in males and females.

Vertebral level	Parameters	Age Group (Years) and sex									
		20-29.9		30-39.9		40-49.9		50-59.9		60-69.9	
		Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
L1	x Vh	27.00	24.00	23.60	23.00	26.40	24.90	25.80	24.50	27.00	22.80
	x Dh	8.50	9.50	10.10	10.50	9.80	10.30	10.00	9.80	8.80	9.00
	I	0.30	0.40	0.40	0.46	0.37	0.41	0.39	0.40	0.32	0.39
L2	x Vh	25.90	25.70	24.90	23.80	27.30	25.00	27.60	25.40	27.40	24.00
	x Dh	9.80	11.00	11.30	10.20	10.70	11.90	11.80	11.80	11.50	10.40
	I	0.38	0.43	0.45	0.43	0.39	0.48	0.43	0.46	0.42	0.43
L3	x Vh	29.00	25.70	25.40	27.70	27.50	24.60	28.00	24.80	27.00	25.20
	x Dh	11.30	12.00	13.10	12.60	12.40	12.80	13.30	12.30	11.80	11.80
	I	0.39	0.47	0.52	0.45	0.45	0.52	0.48	0.50	0.44	0.47
L4	x Vh	27.00	26.00	24.90	23.70	24.10	24.10	27.40	24.70	27.40	24.50
	x Dh	11.50	12.00	11.40	12.60	12.20	12.70	13.80	11.80	11.80	11.60
	I	0.43	0.46	0.46	0.53	0.50	0.53	0.50	0.48	0.42	0.47
L5	x Vh	26.40	27.50	24.90	23.10	25.20	24.00	24.00	23.50	24.90	22.40
	x Dh	9.00	11.50	12.10	12.00	12.70	11.20	12.00	12.50	13.30	13.20
	I	0.34	0.42	0.49	0.52	0.50	0.47	0.50	0.53	0.53	0.59

xVH - mean of midpoint vertebral height; xDh - mean of midpoint disc height; I - Relative disc height index.

the midpoint disc heights increase significantly at the levels of L2/L3 and L3/L4 compared to that reference. This increase ranged from 17% to 29% in males and 17% to 25% in females at the levels of L2/L3 and L3/L4, and represented the maximum heights in younger decades (3rd-5th decades). At the following lower levels L4/L5 and L5/S1, the midpoint disc height displayed age-dependent, though still sex-independent changes. The L4/L5 disc heights remained relatively unchanged or showed minimal insignificant change, while disc heights at L5/S1 tended to decrease in younger age groups namely, 3rd to 5th decades. However, these values showed an obvious increase in older age groups mainly in the 7th decade reaching 50% in males and 47% in females, taking values at L1/L2 as a reference.

Age-dependent changes. In general, changes in midpoint disc heights showed similar non-linear tendencies both in males and females. However, magnitude and significance of these changes exhibited obvious sex-related differences. These changes were clear cut and statistically significant in males, while these changes were less evident and statistically insignificant in females. Midpoint disc heights increased between the 3rd and 4th decade. This increase averaged 17% in males and 5% in females. During the following 5th decade the midpoint disc heights showed a relative but insignificant decrease in males. In females, however, a relative insignificant increase was noticed. This increase represented the maximum values attained relative to the 3rd decade (6%). In the following 6th decade the midpoint disc heights in males reached their maximum values relative to the 3rd decade (22%). In females, these values showed, with the exception of L5/S1 disc, a general decrease. The 7th decade was characterized by decreased midpoint disc heights in both genders, which averaged 13% in males and 11% in females taking the maximum levels for each gender as a reference. However, taking the 3rd decade values as a reference, a net gain of approximately 8% can be seen in males, which becomes more marked at L5/S1 level (48%). In females, although the L5/S1 disc shows a net increase of 15%, the overall tendency of midpoint lumbar disc heights still shows a net decrease averaging 4% relative to the 3rd decade.

Relative disc height index. The relative height indices for all lumbar discs in males and females in each age group are shown in Table 2. Indices remained fairly constant between decades for each disc level in both genders. No significant differences were found between male and female indices.

Discussion.

Accurate knowledge of normal and degenerative lumbar intervertebral discs is of significant practical importance for the surgeon and radiologist alike, for accurate diagnostic interpretation as well as the conduction of interventional and surgical procedures on the lumbar disc. In this regard Dh is an essential measure in the evaluation of normal disc, as well as in the monitoring, management, and follow up of patients with disc degeneration. From a practical point of view, the preliminary step is to decide which methodology to adopt in order to achieve reliable translation of morphological data, obtained through different medical imaging techniques, into numerical values, which in turn could be utilized as parameters. Although conventional radiography is most commonly used to study the intervertebral discs in lateral views,[14-16] the accuracy of the data remains questionable, as different factors can significantly alter the consistency of measurements like position of the patient, distance from the camera and magnification. Computed tomography (CT), on the other hand, allows for the collection of accurate morphometric data of the spine.[17-18] Nevertheless, it is limited to the transaxial plane, and it carries, as with conventional radiography, the risk of exposure to ionizing radiation. Moreover, CT offers only little information about the extent of disc degeneration.[19,20] The MRI technique was adopted in this study for the morphometric evaluation of lumbar spine. This technique, contrary to the previous ones, offers more accurate results and can be performed in any anatomical plane.[21] However it does not expose the patient to ionizing radiation and most importantly, MRI demonstrates disc degeneration clearly.[21-24]

This study is primarily directed at establishing a normal database of lumbar spine measurements for Jordanians thus selection of the test subjects excluded patients with history of lumbar disease or MRI evidence of disc degeneration, or both. In general terms we were able to demonstrate and follow changes of midpoint disc heights in the craniocaudal sequence in each age group as well as changes through successive age groups at each lumbar level with obvious impact of gender. In the absence of signs and symptoms of disc degeneration, these changes can be interpreted in terms of physiological adaptation and explained as a normal reflection of adaptive behavior of the spine to changing functional demands, which by themselves can vary with age and sex. Individual variations related to nutrition, hormonal levels and constitution probably play an additional role. Narrowing of the disc by itself does not necessarily imply disc degeneration.[23] Early changes at the histological level do not alter the Dh significantly, since only advanced degeneration would yield pronounced loss of Dh. In other words, decrease of Dh is proportional to the grade of disc degeneration.[18,24,25]

In the craniocaudal sequence, our results show a clear-cut, sex-independent pattern of increasing midpoint Dh between L1/L2 and L3/L4 (and sometimes L4/L5) in all age groups. This increase seems to follow a regular pattern that remains evident between these levels and in all age groups when these changes are expressed as percentages namely, 17% and 25-29% between L1/L2 and L2/L3 andL1/L2 and L3/L4 in both males and females. In our opinion, this linear increase can be termed physiological, as was described by Biggemann et al.[14] The same principle applies to the observed tendency of decrease of Dh between L4/L5 and L5/S1, which was evident in younger age groups namely, 3rd to 5th decades. Indeed, the lumbosacral disc has been reported to be narrower than other lumbar discs in the absence of degeneration.[13,23] Moreover, our results demonstrate that the height of the lumbosacral disc increases in older age groups in both males and females namely, in the 7th decade. Similar results regarding posterior disc heights though only in females have been described.[13] This increase is accompanied by a wider range of standard deviations, which points to greater individual variability of lumbosacral heights within this age group and indicates a greater susceptibility of this disc to individual differences in the elderly. As a whole, the observed craniocaudal sequences of Dh obviously represent a normal sex-independent pattern in the lumbar spine and can be regarded as physiological in terms of stress adaptation.

In terms of age, our results show a clear increase of lumbar Dh in males between the 3rd and 4th decades averaging 17% as compared to only 5% in females. This increase coincides with the peak of biochemical and structural changes in intervertebral discs as was described by Humzah and Soames.[2] This insignificant increase in females continued as such during the next 5th decade averaging only 6% as compared to 3rd decade, and was followed by insignificant general decrease during the 6th and 7th decades. On the contrary, males attained maximal Dh during the 6th decade to be followed by relative decrease during the 7th decade. A net gain especially in the lumbosacral disc as compared with the 3rd decade can however be demonstrated.

This non-linear, alternating increase/decrease pattern seems to reflect periods of growth and remodeling in relation to changes of functional demands.[13,27] The fact that changes related to Dh in females did not reach the level of significance is probably related to the less demanding nature of functional stress put onto females. This would explain previous reports stating that height of the intervertebral discs increases with aging only in males,[15] as the degree of change is related to physical activity.[28] Moreover, the general pattern of increase or decrease could reflect culture-specific, life style patterns. In Jordan, males and females share an active life during the 3rd and 4th decades. Men in general continue their active life beyond the 4th decade and retire late (60-65 years). Women, on the other hand, retire early (55 years) or even before that time. In general increasing or decreasing patterns of Dh with aging should only be studied within relatively narrow age spans. It is obvious that this alternating pattern can lead to apparent discrepancies between studies when relatively wide age ranges are considered.

Of utmost importance is the observed fact that the relative Dh index (I) remained relatively constant in both males and females through different age groups and at all disc levels. This reflects a coordinated change affecting discs and vertebrae simultaneously. In fact, such age-dependent coordinated changes of discs and vertebrae have been documented morphologically in post mortem studies.[29] In the absence of degeneration, relative height index has also been shown to be constant in males and females.[13] Based on this, relative height index could prove helpful as an indicator for pathological conditions affecting the spine. Significant aberration of this index namely, loss of the constant disc height/ vertebral height relationship could be interpreted as a sign of disc degeneration in terms of altered coordination of disc and vertebral height change. This hypothesis will be considered for future studies.

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