

Diurnal Variation in Lumbar MRI

Correlation between Signal Intensity, Disc Height, and Disc Bulge

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There have been no reports indicating diurnal variations in MRI at different portions of each lumbar disc. Eight asymptomatic healthy volunteers between 22 and 29 years old had MRI of their lumbar spine, twice on the same day (in the morning and evening). Forty lumbar discs were studied and the signal intensity change was measured from three portions of each disc (a total of 120 portions). No visible changes could be detected between scans by blinded observers. However, the calculated signal intensity changes showed an average loss of -20.0% (ant., 5 cases), -19.0% (mid., 2 cases), and -17.5% (post., 1 case). Height loss of the disc showed an average loss of -9.9% (ant., 4 cases), -8.3% (mid., 2 cases), and -10.4% (post., 2 cases). An increase of disc bulge at L4-5 level (18.3%) was pronounced, but L5-S1 level was less than others. Loss of body height averaged a loss of 7 mm (0.39% of body height). There was no correlation between reduced signal intensity and height loss at the ant. / post. portion ($p=0.42$), but there was a close relation at the mid. portion ($p=0.008$). Diurnal change of the disc bulge was not correlated with reduced signal intensity ($p=0.48$) or height loss ($p=0.16$). Intradiscal fluid change was not necessarily influenced by the disc height loss, and height loss did not necessarily have an effect on disc bulge. But diurnal change showed a trend that was reflected in reduced signal intensity, height loss, and an increase of disc bulge which was more apparent from the ant. portion to the post. portion on moving down to the lower levels. Loss of disc height was one factor in the reduction of body height. These changes occurred randomly throughout 5 lumbar disc levels in each case.

Key Words: Lumbar MRI, signal intensity, disc height, disc bulge

Collagen and proteoglycans compose the major macromolecular constituents of the nucleus pulposus, which consists of a network of collagen fibers embedded in a proteoglycan gel. The nucleus pulposus consists of 80~90% water. The water content of the gel is variable and represents an equilibrium between

two opposing pressures: the mechanical pressure, which dehydrates the gel, and the swelling pressure of the hydrophilic proteoglycans, which causes the gel to absorb fluid. The hydrostatic properties of the nucleus pulposus arise from its high state of hydration: The hydrophilia of the disc is not strictly biochemical, as diurnal variations in disc height indicate water can be squeezed out under pressure (White and Gordon, 1982; Adams and Hutton, 1983).

This flow of fluid in and out of the disc alters its height and is related to disc nutrition. Some investigators believe that water fluctuation within

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the intervertebral disc is responsible for this height (Depuky, 1935; Modic *et al.* 1984; Reilly *et al.* 1984; Jazwinska and Adam, 1985; Krag *et al.* 1990; Boos *et al.* 1993). Methods of assessment frequently involve ionizing radiation (plain radiographs and CT scans) and a more invasive approach including the injection of intrathecal or intradiscal contrast material (myelography, high-resolution CT with contrast agents, or discography). The use of magnetic resonance imaging (MRI) to diagnose spine disorders has dramatically increased over the last 10 years. MRI can provide the same or even increased anatomical and biological information without irradiation or invasive procedures. In fact, many observers believe that MRI has become the procedure of choice for lumbar spine imaging. Given that MRI is quite sensitive to hydrogen proton density and water content, it follows that diurnal water fluctuation within the intervertebral disc may be detectable with MRI (Modic *et al.* 1983; Moon *et al.* 1983; Pearce *et al.* 1991). LeBlanc *et al.* (1984) showed that signal intensities of the vertebral disc decreased after patients had been kept at bed rest for 5 weeks. Urban and Maroudas (1979) showed that there is very little fluid flow when the loading of the disc fluctuates rapidly, such as during walking. However, the diurnal cycle of erect and supine posture implies that the large changes in pressure acting over long periods of time will result in considerable fluid exchange.

The purpose of the present study was to test our hypothesis: Given variations in the time of day when MRI scanning is performed, 1) the degree of change in disc signal intensity correlates directly with the degree of height loss, 2) the disc signal intensity and height at the posterior portion of each disc decreases more than at the anterior or mid portion, 3) the degree of disc bulge correlates directly with the degree of height loss or reduced signal intensity, and 4) disc height loss influences loss of body height.

We have attempted to establish an understanding of the normal dynamic phenomena of disc hydration during the course of a day and how much influence it has on changes in disc and body height. We also thought this study could form the basis for making further studies of symptomatic patients (herniated disc, degenerative disc and vertebra).

MATERIALS AND METHODS

Eight volunteers between 22 and 29 years old were included in this study. There were five men and three women. Each volunteer underwent a thorough medical history and physical examination. They had to have had no prior or current history of lumbar, buttock or leg pain and no other historical features of active lumbar pathology. They also had to have normal results from a complete musculoskeletal and neurological examination. Each volunteer had the lumbar spine scanned twice on the same day; The first scan (AM scan) was performed 1 to 1.5 hours after waking. Before performing an MRI scan, volunteers would lie down for 1 hour in a Fowler position (supine, with legs on a block and hips and knees flexed) to achieve minimal spinal loading. This position allowed a more rapid recovery of the initial fluid loss. After the AM examination, volunteers went about their usual 8-hour working day, including sedentary activity. In the afternoon, a second MRI examination (PM scan) was performed, using AM scout film so as to reduce the error. Lumbar disc levels L1-2, L2-3, L3-4, L4-5, and L5-S1 were studied, using a middle sagittal T2 image (Fig. 1). We divided the distance (A-P diameter) between the anterior and posterior annulus fibrosus into three portions at each disc level (the anterior, middle, and posterior portion. Fig. 2). The imaging protocol consisted of a sagittal T2-weighted spin echo sequence with TR of 2500 msec and TE of 80 msec; 256 x 256 matrix; field of view, 280mm; 4-mm thick section, using a 1.5-Tesla Siemens magnet. A 5-inch rectangular coil was used for high signal-to-noise resolution.

A saline phantom was used in each scan as a control to identify any signal changes that might occur by virtue of coil tuning or developing (Fig. 1). The saline phantom consisted of a 300 ml bag of normal saline taped in the midline to the volunteer's skin overlying the lumbar spine. The area of signal intensity was measured by circular cursor available on the MRI console. ROI (region of interest) was 0.3 cm², corresponding to 0.12 cm³ of disc (4-mm thick sections).

The area of signal intensity measurement was

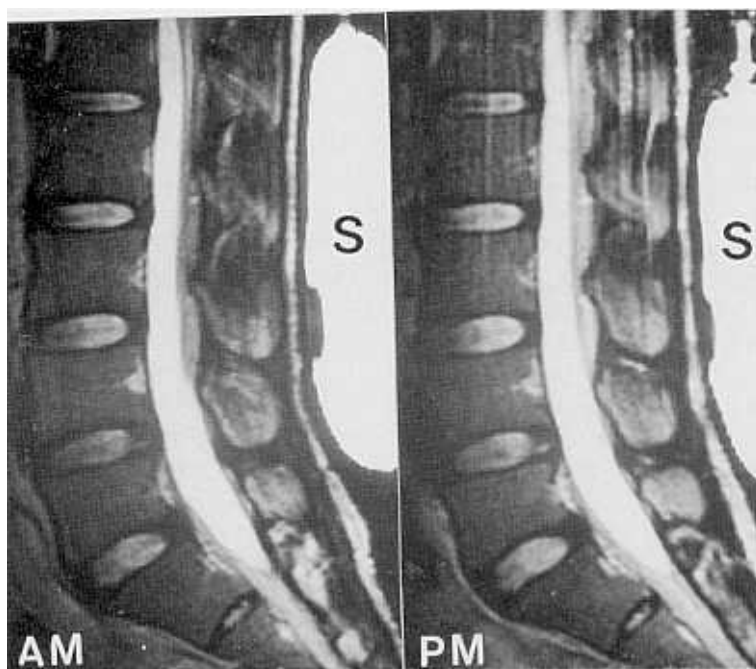


Fig. 1. T2-weighted MRIs of the same patient scanned at different time of the day. At left is the sagittal view in the morning (AM); at right is the same view in the evening (PM). No visible change can be detected between AM and PM. "S" indicates the saline phantom.

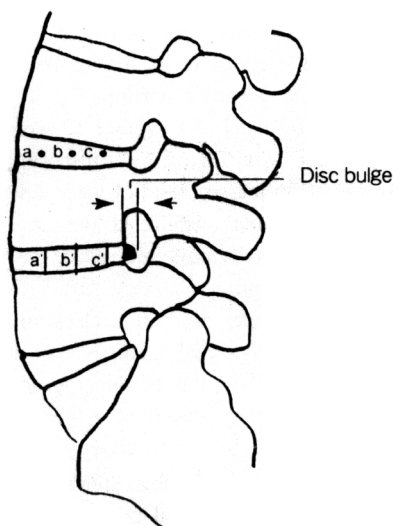


Fig. 2. Schematic drawing shows the measuring method for height, signal intensity and disc bulge in each disc: anterior (a) / middle (b) / posterior (c) portions; a', b', c': disc height, a, b, c: disc signal intensity.

mid-point in each portion between the vertebral end plates. Three signal intensity values at each portion of disc level were recorded for the AM and PM scans. Three values were then averaged to give one AM and one PM signal intensity value for each portion of each disc level. A ratio was then derived for each portion of each disc level by dividing its average signal intensity by the average of the saline phantom signal intensity. A percentage change from AM to PM was calculated by subtracting the AM ratio value from the PM ratio value and dividing by the AM ratio value. A negative percentage change represented a loss in signal intensity.

The change in disc height was noted for each intervertebral disc level on the AM and PM scans. A percentage change for each disc level was derived by the same method. A negative result indicated a loss of height diurnally.

The disc bulging was defined as any smooth focal extrusion of the disc beyond the line which connected between the upper and lower posterior edges

of the vertebral body at each disc level. The degree of disc bulging was indicated the length to draw a line perpendicular to that line (predescription) from the maximal point of disc bulge. The percentage change was measured by the same method. A positive result indicated more disc bulging in the afternoon than in the morning.

The change of body height was measured at the same time and a percentage change was similarly derived.

The change in signal intensity, disc height and disc bulge were compared at each disc level to determine a specific correlation. A statistical analysis was performed using the Student t-test and Pearson's

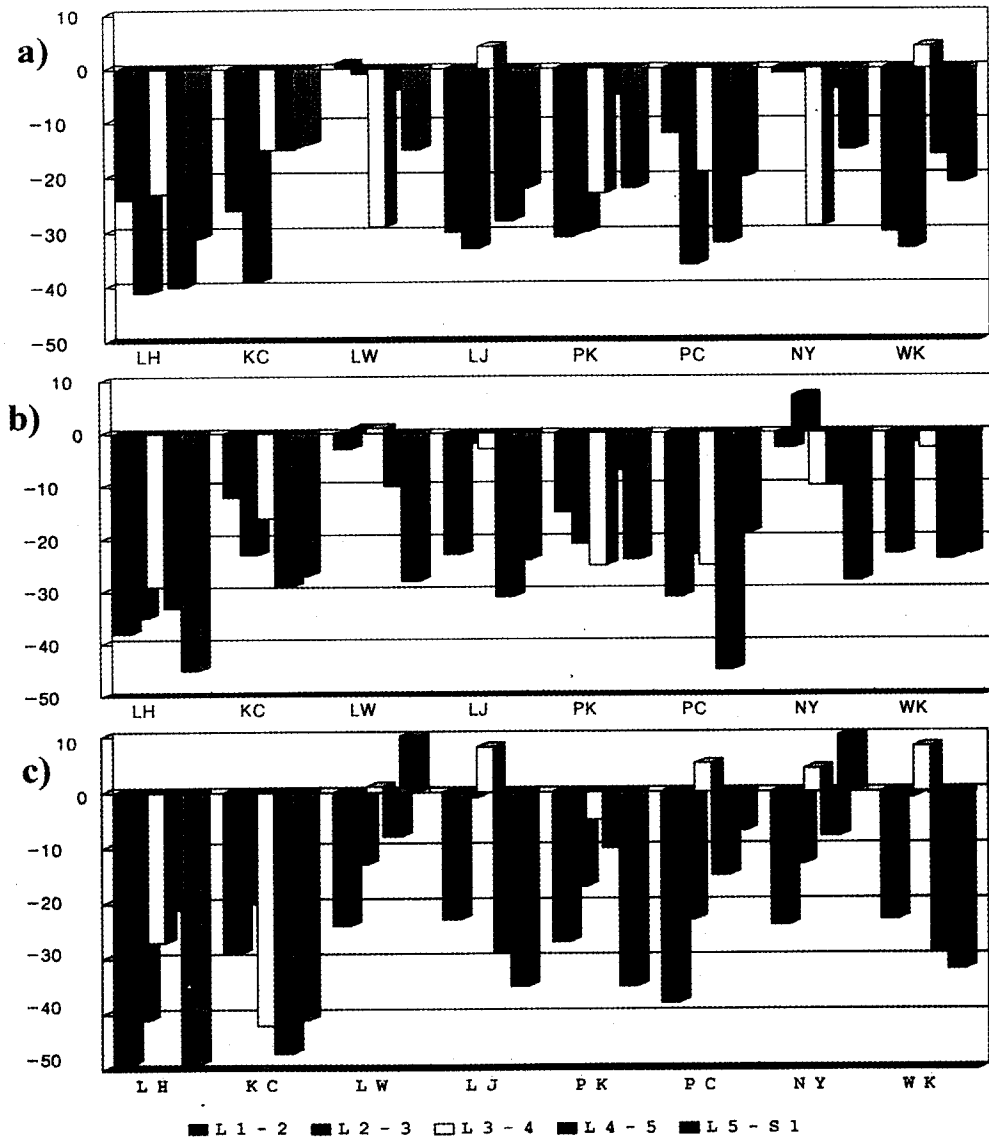


Fig. 3. Percent change in signal intensity a) ant. portion. 37 of 40 discs showed a decrease and more decreased at L2-3. b) mid. portion. 37 of 40 discs decreased and more decreased at L4-5. c) post. portion. 32 of 40 discs decreased and more decreased at L1-2/L5-S1.

correlation analysis. A p-value of < 0.05 was taken to indicate statistical significance.

RESULTS

We found measurable gains and losses of signal

intensity in different discs during the course of the day. Fig. 3 shows the percentage change in signal intensity of the vertebral discs as determined by computer grading (a; anterior portion, b; mid portion, c; posterior portion). The average change in signal intensity at "a" portion was -20.0% (range $+4\%$ to -41%), representing a loss of signal in-

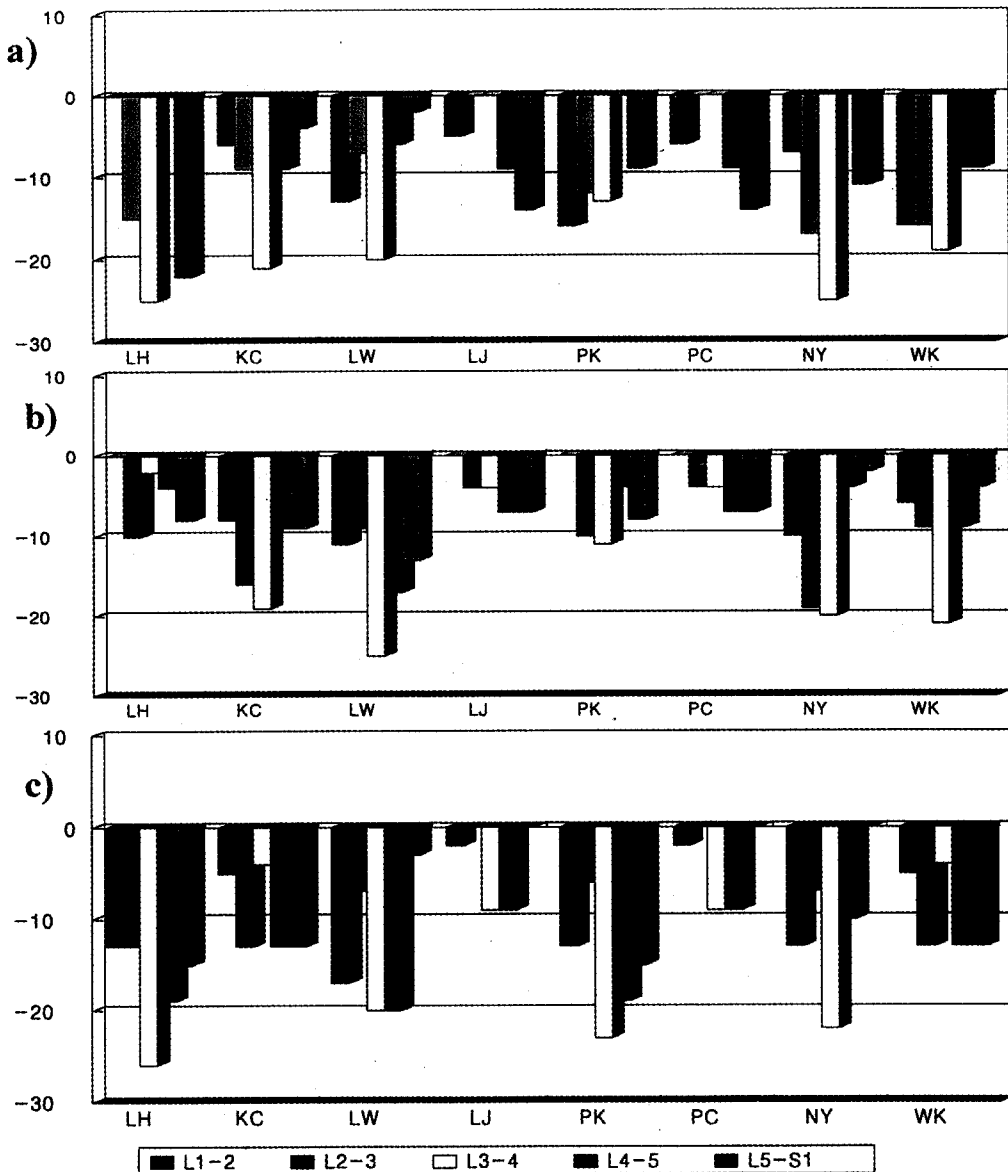


Fig. 4. Percent change in disc height a) ant. portion. 33 of 40 discs showed a loss of disc height and b) mid. portion 37 of 40 discs showed a loss of disc height c) post. portion. 37 of 40 discs showed a loss of disc height. But more lost at L3-4. disc level.

tensity from AM to PM. Measurement of signal intensity found 37 of 40 discs (92.5%) had a decrease in signal intensity ($p < 0.0007$), but 3 portions had an increase. The average changes in signal intensity at "b" and "c" portion were -19.0% (range $+7\%$ to -45%) and -17.5% (range $+14\%$ to -49%). 37 of 40 discs (92.5%) had a decrease and 3 portions had an increase in signal intensity at "b" portion ($p < 0.0001$). At "c" portion, 32 of 40 discs (80%) had a decrease and eight had an increase in signal intensity ($p < 0.007$). Statistical analysis of the changes in disc signal intensity from AM to PM as graded by the MRI computer found the majority of discs had a decrease in intensity. Diurnal change in signal intensity at each portion varied, but signal intensity change seemed to be more pronounced at "a" portion compared to "b" and "c" portion; 5 cases had a decrease at "a" portion, 2 cases at "c" portion and 1 case at "b" portion. Signal intensity at L2-3 disc level (5 cases) showed a tendency to be more decreased at "a" portion, L4-5 (4 cases) at "b" portion, and L1-2 / L5-S1 (4 cases) at "c"

portion (Table 1). However, these signal intensity changes occurred randomly throughout the five lumbar disc levels in each case.

Fig. 4 shows the percentage change in disc height.

Table 1. Case distribution in signal intensity(1) and in height loss (2) of disc levels

(1)	level					
	portion	L1-2	L2-3	L3-4	L4-5	L5-S1
	anterior	1	5	2		
	mid			1	4	3
	posterior	4*			1	4*

(2)	level					
	portion	L1-2	L2-3	L3-4	L4-5	L5-S1
	anterior	1		5		2
	mid		1	5	2*	2*
	posterior		2	6*	5*	2*

*: overlapping case

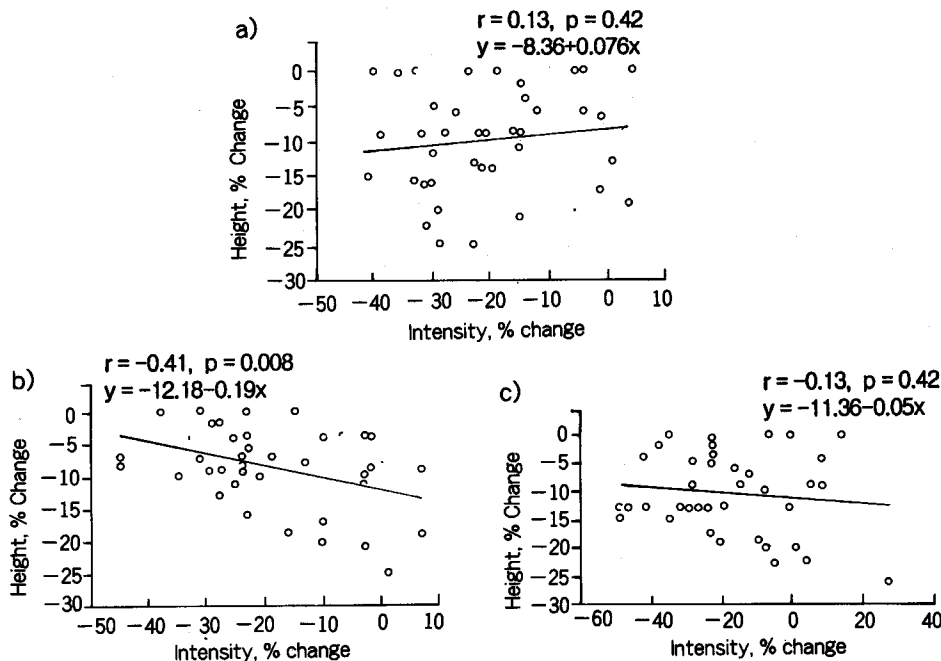


Fig. 5. Correlation between changes of signal intensity and disc height. a) ant., b) mid, c) post. portions. No correlation between changes of disc height and signal intensity at a) / c), but a correlation was made at b).

The average change was -9.9% (range 0% to -25%) at "a" portion ($p < 0.0001$). Thirty three of 40 intervertebral discs (82.5%) lost height and seven of 40 (17.5%) had no change in height. The average changes at "b" and "c" portion were -8.3% (range 0% to -25%) and -10.4% (range 0% to -26%).

Thirty seven of 40 discs (92.5%) lost height at "b" and "c" portion ($p < 0.0001$) and three (7.5%) had no change. Four cases had a height loss at "a" portion, two cases had a height loss at "b" portion and the

other two cases had a height loss at "c" portion. Height loss at the L3-4 disc level showed a tendency to be more pronounced at all portions (Table 1). These data showed the height loss at "a" and "b" portion to be about 10% of disc height in the morning and at "c" portion to be about 8% . Going down from the upper level to the lower level of lumbar discs, the reduced signal intensity and height loss showed a tendency to increase from the ant. portion to the post. portion. There is no correlation

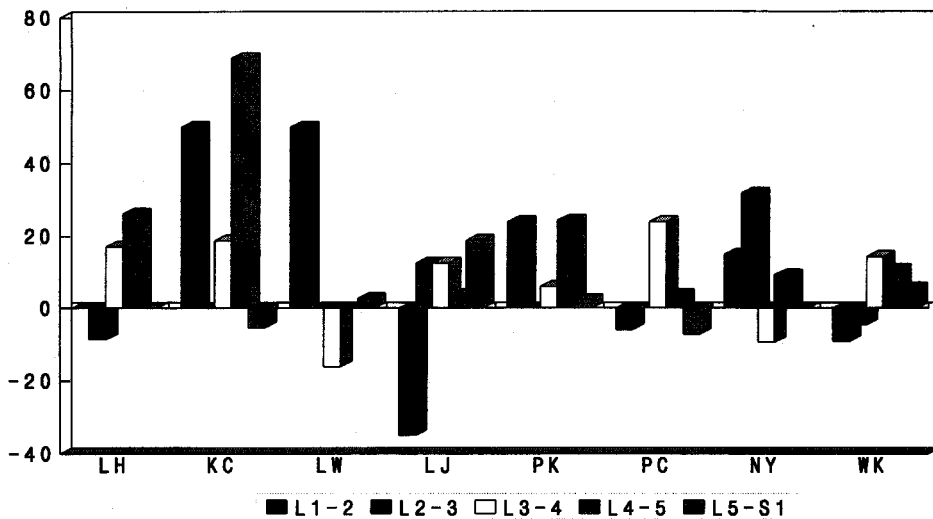


Fig. 6. Diurnal percent change of disc bulge. Twenty three of 40 discs showed an increase in disc bulge, 9 of 40 discs lost disc bulge, and 8 of 40 discs showed no change. But 8 volunteers showed a trend to decrease in total disc height.

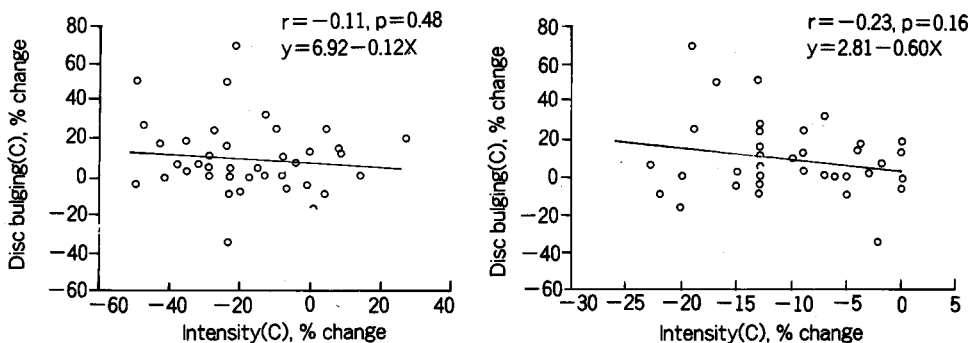


Fig. 7. Correlation of change in disc bulging with changes of signal intensity and height. No correlation between changes of disc bulging and signal intensity ($p = 0.48$) and between changes of disc bulging and height loss ($p = 0.16$).

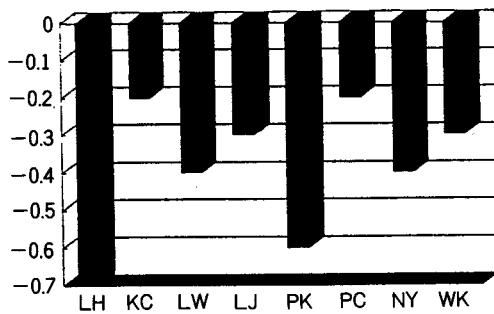


Fig. 8. Percent change in body height. All 8 volunteers had a decrease in body height.

between reduced signal intensity and loss of disc height at "a" and "c" portion ($r = 0.13$, $p = 0.42$; $r = -0.13$, $p = 0.42$), but the correlation could be made at "b" portion ($r = -0.41$, $p = 0.008$) (Fig. 5).

Fig. 6 shows the percentage change in disc bulging from morning to afternoon. Twenty three of 40 discs (57.5%) had an increase in disc bulge, nine of 40 (22.5%) lost disc bulge, and eight of 40 (20%) had no change in disc bulge. All cases had an increase of disc bulge and the average change was 8.8%. The increase in disc bulge at L4-5 level (7 cases) was more pronounced than other levels. But diurnal changes in disc bulging varied ($p < 0.18$) and no correlation could be made, not only between reduced signal intensity and disc bulging ($r = -0.11$, $p = 0.48$), but also between the loss of disc height and disc bulging ($r = -0.23$, $p = 0.16$) (Fig. 7).

Fig. 8 shows the percentage change in body height from morning to afternoon. All 8 cases had a decrease in body height, the mean daily height loss for each subject was 0.39% of body height, approximately 7 mm, with a range of 3 mm to 12 mm.

We found gains and losses of signal intensity accompanied by a change of disc height in different discs during the course of the day.

DISCUSSION

The intervertebral disc is composed of three distinct parts: 1) the cartilaginous end plate composed of hyaline cartilage which plays a key role as a

biomechanical and metabolic interface between the vertebral body and nucleus pulposus; 2) the annulus fibrosus whose purpose is to resist radial tension induced by axial loading of the disc as well as stresses from torsion and flexion; 3) the nucleus pulposus, which is composed of well-hydrated, loose, delicate fibrous strands forming a noncompressible gelatinous matrix. The nucleus pulposus consists of a network of collagen fibers embedded in a proteoglycan-water gel. The water content of the gel is variable and represents an equilibrium between two opposing pressures: mechanical pressure which dehydrates the gel; and the swelling pressure of the hydrophilic proteoglycans which causes the gel to absorb fluid (Conventry *et al.* 1945; Conventry, 1969; White and Gordon, 1982). Any change in the loading of the disc will disturb this equilibrium and fluid will flow until a new balance is achieved. The change of fluid like this alters the height of the disc followed by changes affecting the size of the intervertebral foramen and modifying joint mechanics (Adams *et al.* 1990).

Previously, the variation in water content of the intervertebral disc could only be studied in vitro (cadaver) or by indirect means such as measuring intradiscal pressure, body height, or range of lumbar flexion (Adams and Hutton, 1983; Tyrrell *et al.* 1985; Sullivan and McGill, 1990). However, signal intensity in MRI is closely related to water protons and relaxation times are influenced by the interactions of water molecules with their environment. Quantitative MRI provides the potential to directly study the water content variations in vivo. Thus, loss of brightness in any region must be attributed either to the relative deficiency of water in that region or to the interaction between tissue water and other tissue macromolecules, such as collagen or proteoglycan (Modic *et al.* 1984; Modic *et al.* 1988; Modic and Ross, 1991; Pearce *et al.* 1991). Pearce *et al.* (1991) said that brightness could not depend on the water concentration alone and, on the contrary, collagen and proteoglycan concentrations in the nucleus demonstrated a trend toward a higher mean value. But many investigators have reported that the relative brightness of a region weighted spin echo MRI of disc tissue is sensitively influenced by water content variations (LeBlanc *et al.* 1984; Modic and Ross, 1991; Boos *et al.* 1993).

In the morning, the posterior annulus is higher than at the end of the day and nucleus pulposus has a higher fluid content. As fluid flow is approximately proportional to the area and inverse square of the path length, this could explain the greatly increased loss of fluid from the nucleus. The fluid loss in flexed postures was 10 times greater compared to erect postures. Flexion movements performed in the early morning generate much higher stresses in the osteoligamentous lumbar spine than do similar movements later in the day (Adams and Hutton, 1982, 1983).

The changes in disc signal intensity from AM to PM show the majority of discs had a decrease, which was more pronounced at "c" portion going down to lower levels. Results show the signal intensity change was more pronounced at "a" portion (5 cases, 20%) than at "b" (2 cases, 19%) and "c" portion (1 case, 17%). According to disc level, L1-2 and L5-S1 level (5 cases) showed more decrease at "c" portion, L2-3 level at "a" portion, and L4-5 level at "b" portion than others. We think these results may be determined by lumbar anatomical features (weight-bearing center, ligaments, curvature). However, these signal intensity changes occurred randomly throughout 5 lumbar disc levels in each patient. We found that our previous belief of more decrease at "c" portion was wrong. An increase in the signal intensity showed in a few portions (3 of 40 discs at "a" and "b" portion, and 8 of 40 discs at "c" portion). We suggest that these would depend on how long they have been at rest before performing the afternoon (PM) MRI scan. That is because if the volunteers had been at rest for hours after active working, swelling pressure would increase rapidly (decrease in mechanical [hydrostatic] pressure). We attribute this to the overcompensating rebound phenomenon.

The reduced average change in total disc heights was 9.9% (4 cases) at "a" portion, 8.3% (2 cases) at "b" portion, and 10.4% (2 cases) at "c" portion. Height loss at L3-4 level was more pronounced than at other levels. We don't exactly know the reason, but that level was mid-portion of the lumbar vertebrae. We suspect that it may be effected by downward pressure from weight bearing and upward pressure from the sacropelvic fixation system. But we could not find any significant correlation between

signal intensity change and height loss of the intervertebral disc. We confirmed that our hypothesis was mistaken and that these height loss changes occurred randomly throughout 5 lumbar disc levels in each patient.

Silcox *et al.* (1995) reported an increase in disc bulge in 17 (48.6%) of 35 discs. Our studies showed an increase in disc bulge was measured in 23 (57.5%) of 40 discs. Of note is that an increase in disc bulge at L4-5 level was more than at other levels. We suggest that it may be because the L5 vertebra was fixed at sacrum and pelvis with many ligaments. According to these data, the most reduced signal intensity at the "c" portion is at L1-2 / L5-S1, the most loss of disc height at the "c" portion is at L3-4, and the most disc bulge is at L4-5. But there is no correlation of increased disc bulge with diurnal reduced disc signal intensity and loss of disc height. Previous studies in cadaver specimens have shown a correlation between loss of disc water, loss of disc height and increased disc bulge diurnally in the lumbar disc (Adams and Hutton, 1983; Adams *et al.* 1990). We suggested that they might check only at "b" portion in our model, because a correlation could be made only at "b" portion in our studies. We suggest that the segmental nerve root may be affected in the afternoon not only by extra radial bulging of the disc, but also by other factors (reduced height of the intervertebral foramen, buckling of the ligament flavum, and osteoligamentous components). But diurnal changes in disc bulge varied ($p < 0.18$).

Kraemer and Gritz (1980) measured the standing height of 108 subjects at 7:00 A.M., 10:00 AM, and 8:00 PM: 62-to-71% at 10:00 AM (3 hours upright) and 83-to- 85% at 1:00 PM (6 hours upright). Reilly *et al.* (1984) reported that 54% and 80% of the total height loss occurred at 1 hour and 3 hours respectively. DePuky (1935) has stated that the overall average height loss was 15.7 mm and the loss of body height during the day is due to loss of disc height, and the mean loss decreased with age (approximately 2% at 5 years, 1% at 20 years, and 0.5% at 80 years). Adams and Hutton (1983) reported that old and degenerated discs lost a smaller percentage of fluid than did young and nondegenerative discs. Discs of people under the age of 35 lose almost twice this amount (Depuky, 1935). Krag *et al.*

(1990) have recorded an overall height loss throughout the day of approximately 16 mm. Our studies showed that all cases had a decrease in body height, approximately 7 mm (0.4% of body height). Age range in our volunteers was between 22 and 29 years old. We don't know about the exact correlation between loss of body height and age because our studies were not in a wide age range, but we agree with reports that body height loss decreases with age. On growing older, disc material was degenerated and loss of disc fluid increased. We suggest that the diurnal change of body height may be less in old age. Our studies showed that the loss of body height during the day was affected by the loss of disc height ($p < 0.007$). Our studies only related to a small sample size and further work is required with a larger group.

First, we would like to observe whether symptomatic patients' discs behave differently, and second, whether the loss of disc height and signal changes are affected by spine motion (flexion, sitting, extension) and the aging process. However, by measuring signal intensity in normal asymptomatic patients, we wanted to establish an understanding of the normal dynamic phenomena of disc hydration during the day.

In summary, the time of day that MRI was obtained influenced the signal intensity of the lumbar disc. There is a diurnal variation in the fluid content and height of the discs which causes a variation in the mechanical properties of the spine. Signal intensity changes and loss in disc height showed a tendency to be increased at the anterior portion of most discs. A loss of signal intensity did not necessarily correlate with a loss in disc height or an increase in disc bulge because these changes occurred randomly throughout the five lumbar disc levels in each patient. On going down to lower levels, the posterior portion was more decreased. A loss in disc height was one factor in the reduction of body height.

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