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## **Association between Annular Tears and Disk Degeneration: A Longitudinal Study**

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# Association between Annular Tears and Disk Degeneration: A Longitudinal Study

**BACKGROUND AND PURPOSE:** Annular tears and nuclear degeneration often occur concurrently, but their temporal association remains unknown. The purpose of this study was to assess whether annular tears precede nuclear degeneration and whether the evolution of nuclear degeneration is affected by presence of annular tears.

**MATERIALS AND METHODS:** From our radiology report data base, 46 patients with back pain were identified, each with 2 previously obtained lumbar spine MR imaging examinations in the absence of any spinal intervention. Two neuroradiologists evaluated intervertebral disks between the T12 and S1 segments in a random blinded fashion. Hyperintense foci within the annulus were noted to diagnose annular tears. The signal intensity of disks was graded on an ordinal scale, and overall degeneration, on the scale of Pfirrmann et al. Mean signal-intensity and degeneration grades were calculated for disks with and without annular tears, and differences were tested for statistical significance. Mean changes in these grades on follow-up studies were also calculated and compared for 2 groups.

**RESULTS:** The study included 13 men and 33 women, with a mean age of  $53.6 \pm 15.2$  years (range, 20–88 years). The mean interval between the imaging studies was 31.8 months. Annular tears were seen in 203 of 276 (73.5%) disks. Twenty-one of these had normal central signal intensity. Compared with disks without annular tears, disks with annular tears demonstrated significantly higher degeneration grades and a higher change in these grades on follow-up.

**CONCLUSIONS:** Annular tears occur in the early stages of disk degeneration and are associated with a faster subsequent nuclear degeneration.

A strong association between annular tears and nuclear degeneration has been well demonstrated in a number of earlier studies involving a single observation of intervertebral disks.<sup>1,2</sup> The natural history of the disk degeneration, however, still remains poorly understood, with the relative timing of the development of annular tears and their long-term association with nuclear degeneration being unclear. To define this process better, previous authors have studied cadaveric spines to determine the prevalence of various morphologic and histologic changes in the annulus fibrosus and nucleus pulposus at different ages.<sup>3–6</sup> These studies are, however, limited in their scope to a single observation and do not provide a clear picture of the natural evolution of disk degeneration. A long-term observation of the disks can be expected to provide a useful insight into this process.

A number of previous longitudinal investigations have used MR imaging to study the sequential changes in various aspects of disk morphology in asymptomatic individuals or monozygotic twins.<sup>7–12</sup> However, these articles have mainly assessed the influence of genetics or environmental variables on the progression of overall disk degeneration in individual

subjects, without focusing on the possible association of sequential degeneration of individual disks with annular tears.

The purpose of our study was to observe the natural history of disk degeneration for a period of time, with special reference to its association with the annular tears. We wanted to test 2 specific hypotheses. Our first hypothesis was that annular tears precede the appearance of nuclear degeneration. Second, we hypothesized that disks with annular tears are associated with more rapid nuclear degeneration. We investigated this retrospectively using pre-existing data in patients with back pain who had undergone multiple lumbar spine MR imaging studies. Imaging in these patients often reveals overt pathologic changes affecting some intervertebral disks while sparing others. If our first hypothesis was true, we expected to find many disks with annular tears, but without nuclear degeneration. At the same time, there would be a paucity of disks showing obvious signs of nuclear degeneration in the absence of annular tears. The follow-up MR imaging of these patients provided us with the longitudinal data needed to test the second hypothesis.

## Materials and Methods

This retrospective study was approved by the institutional review board of our hospital.

## Patient Selection

We initially queried our radiology report data base to identify patients whose reports showed reference to a prior MR imaging examination with the clinical indication of back pain. The radiology and clinical data base on these patients was then accessed to exclude patients with spondylodiskitis, spinal tumors, or fractures of the lumbar spine. Patients with spinal surgery or other spinal interventions, such as discectomy, vertebroplasty, or spinal biopsy performed in the interval between the 2 MR imaging examinations, were also excluded. The

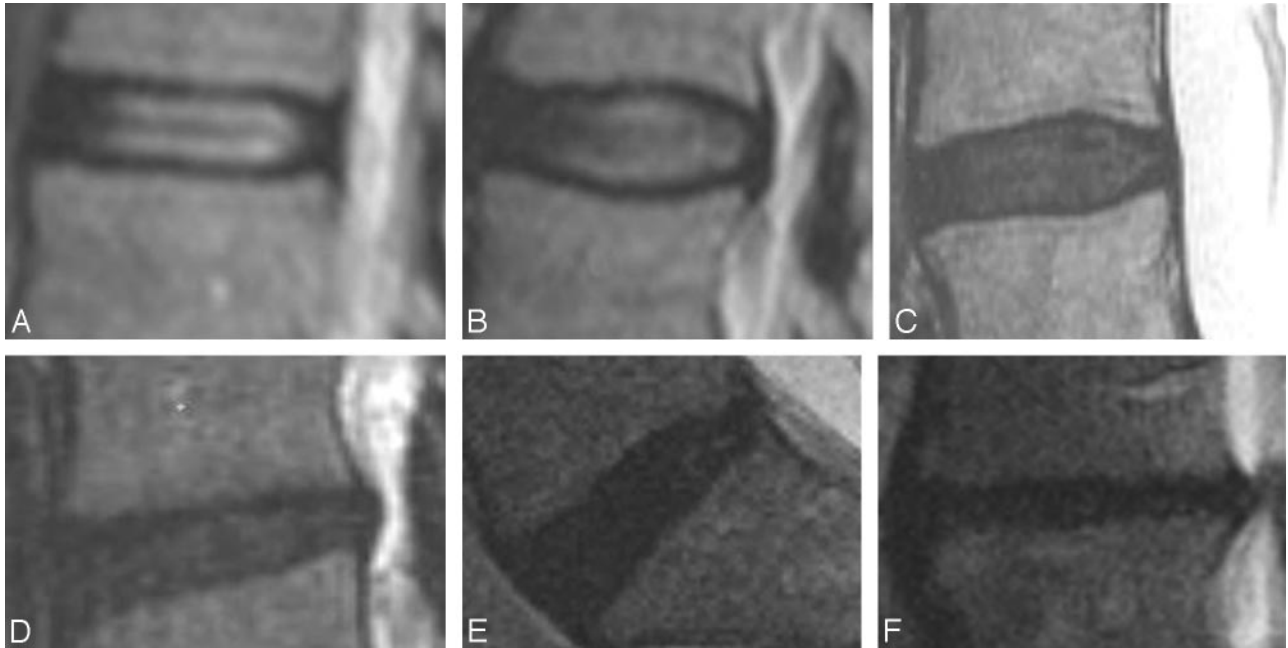
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**Fig 1.** The signal-intensity grading scale. Grade 1 (A) implies a normal disk with preserved signal intensity in the central aspect. Grades 2–5 (B–E) represent disks with areas of signal-intensity loss affecting <25%, 26%–50%, 51%–75%, and 76%–99% of the central disk volume. No appreciable central hyperintensity is noted in Grade 6 (F). All images extending through the disk were taken into consideration at the time of assigning the signal intensity grade.

search continued until a total of 50 patients was reached after the initial exclusions.

### MR Imaging Analysis

Two full-time neuroradiologists (with 8 and 23 years of postfellowship experience) read the studies by consensus. The accession numbers of all studies were arranged in a random order, and the readers evaluated the studies in that order. The readers did not know whether they were evaluating the initial or follow-up study on a given patient. If the readers encountered the other study on a patient within the same week, evaluation of that study was withheld, and such studies were evaluated >2 weeks later to prevent a recall bias. For each study, 6 intervertebral disks between the T12 and S1 levels were analyzed for signal-intensity grade, degeneration grade, and the presence of annular tears. The annular tears were also graded for conspicuity. Disks were evaluated by reviewing sagittal and axial T2-weighted turbo spin-echo images, which were available in all patients. Various definitions used to characterize these parameters are given below.

### Signal-Intensity Grade

An arbitrary scale was created to assess the extent of signal-intensity loss on T2-weighted images involving the central aspect of the disk, from grades 1 through 6 (Fig 1). Disks were graded after assessing their entire extent on sagittal T2-weighted turbo spin-echo images. Grade 1 was assigned to the disks demonstrating normal bright signal intensity in the central portion, whereas Grade 6 implied complete absence of bright signal intensity in that portion. Grades 2–5 represented loss of signal intensity affecting <25%, 26%–50%, 51%–75%, and 76%–99%, respectively, of the central aspect of the disks.

### Degeneration Grade

The extent of overall degeneration of the disks was graded on a scale suggested by Pfirrmann et al.<sup>13</sup> This scale takes into account multiple morphologic changes observed in the degenerated disks, such as ho-

mogeneity of signal intensity, presence of horizontal clefts, distinction between the anulus and nucleus pulposus, and disk height. Grade 2 on this scale denotes the inhomogeneous appearance with or without the appearance of horizontal clefts within the central aspect of the disk. The distinction between the anulus and the nucleus becomes unclear in stage 3. Stage 4 disks show hypointensity, with normal to moderately decreased disk height, whereas stage 5 refers to a collapsed disk.

### Annular Tear and Annular Tear Conspicuity

The presence of any hyperintense signal intensity within the peripheral anulus was considered to represent an annular tear. The conspicuity of the annular tears was graded on a scale ranging from 1 (signal intensity matching that of CSF) through 4 (presence of probable subtle intermediate signal intensity in the peripheral anulus). Grade 2 tears represented an obvious hyperintensity, though less intense than CSF. Grade 3 was assigned to tears showing definite but less conspicuous intermediate signal intensity in the peripheral anulus. For tears varying in conspicuity along their extent, the grading was based on the most conspicuous region.

### $\kappa$ Analysis

The reliability of our technique was tested by a repeat assessment of 60 intervertebral disks (in 10 patients) after an interval of >7 months and by comparing original and repeat assessments with  $\kappa$  analysis.

### Statistical Analysis

The first hypothesis, that annular tears precede nuclear degeneration, was evaluated indirectly by comparing the frequency and severity of nuclear degeneration on initial MR imaging in disks with and without annular tears. A more direct testing of the first hypothesis was also done by observing the changes on follow-up of the disks that were normal on the first MR imaging. Mean signal-intensity grade and mean degeneration grade were calculated for the disks with and without annular tears. Calculations were done for all disks collectively, as

**Table 1: Mean ( $\pm$ SD) initial signal-intensity and degeneration grades and changes in them by annular tear for all disks and by disk level**

Disk	Annular Tear?	Initial Signal-Intensity Grade	Initial Degeneration Grade	Change in Signal Intensity	Change in Degeneration
All	No	1.43 $\pm$ 0.62	2.20 $\pm$ 0.40	0.15 $\pm$ 0.54	0.15 $\pm$ 0.39
	Yes	3.07 $\pm$ 1.31	3.24 $\pm$ 0.94	0.42 $\pm$ 0.85	0.31 $\pm$ 0.37
T12-L1	No	1.50 $\pm$ 0.50	2.19 $\pm$ 0.40	0.11 $\pm$ 0.43	0.23 $\pm$ 0.42
	Yes	2.60 $\pm$ 1.42	2.90 $\pm$ 1.02	0.40 $\pm$ 0.88	0.30 $\pm$ 0.57
L1-2	No	1.27 $\pm$ 0.57	2.22 $\pm$ 0.43	0.27 $\pm$ 0.43	0.05 $\pm$ 0.23
	Yes	2.87 $\pm$ 1.2	3.14 $\pm$ 0.93	0.46 $\pm$ 0.79	0.25 $\pm$ 0.51
L2-3	No	1.53 $\pm$ 0.90	2.20 $\pm$ 0.41	0.06 $\pm$ 0.70	0.13 $\pm$ 0.56
	Yes	2.90 $\pm$ 1.16	3.16 $\pm$ 1.00	0.38 $\pm$ 0.80	0.32 $\pm$ 0.59
L3-4	No	1.50 $\pm$ 0.52	2.30 $\pm$ 0.48	0.20 $\pm$ 0.63	0.10 $\pm$ 0.41
	Yes	3.25 $\pm$ 1.33	3.30 $\pm$ 0.85	0.33 $\pm$ 0.92	0.41 $\pm$ 0.55
L4-5	No	1.00 $\pm$ 0.00	2.00 $\pm$ 0.00	0.50 $\pm$ 0.70	0.50 $\pm$ 0.72
	Yes	3.25 $\pm$ 1.31	3.36 $\pm$ 0.96	0.40 $\pm$ 0.87	0.25 $\pm$ 0.57
L5-S1	No	1.50 $\pm$ 0.70	2.00 $\pm$ 0.00	-0.50 $\pm$ 0.90	0.00 $\pm$ 0.00
	Yes	3.22 $\pm$ 1.37	3.34 $\pm$ 0.91	0.56 $\pm$ 0.87	0.34 $\pm$ 0.64

**Table 2: Results of mixed-model analysis of signal-intensity grade and degeneration grade**

	Initial Signal-Intensity Grade	Initial Degeneration Grade	Change in Signal Intensity	Change in Degeneration
Disk	$P = .003$	$P = 0.002$	$P < .0001$	$P < .0001$
Initial annular tear	$P < .0001$	$P < .0001$	$P < .0001$	$P < .0001$
Stage	–	–	$P < .0001$	$P < .0001$
Time between studies	–	–	$P = 0.98$	$P = .70$

Patient was treated as a random effect, and disk and presence of an annular tear on initial MR imaging were treated as fixed effects on all the analyses. Initial signal-intensity and degeneration grades were used as the dependent variables to analyze patterns at baseline. Signal-intensity grade and degeneration grade for both stages (initial, follow-up) were the dependent variables, and stage was added as a fixed effect, to analyze change, as was the time between studies, to control for differences between patients.

well as for each segmental level. The second hypothesis (disks with annular tears show faster nuclear degeneration) was tested by comparing changes in signal-intensity and degeneration grades between initial and follow-up studies for disks with and without annular tears. Mixed-model analysis was used to test patterns for statistical significance because analysis showed relatively strong cluster correlations of disks within patients and mixed-model analysis is a relatively simple way to account for correlated data. The patient was treated as a random effect, and disk (referring to segmental level) and presence of an annular tear on initial MR imaging were treated as fixed effects on all the analyses. Initial signal intensity and degeneration grades were used as the dependent variables to analyze patterns at baseline. Signal-intensity intensity grade and degeneration grade for both stages (initial and follow-up) were the dependent variables, and stage was added as a fixed effect to analyze change, as was time between studies to control for differences between patients. A  $P$  value of  $<.05$  was considered significant.

## Results

Of the 50 patients initially identified, 4 were excluded, 3 for the nonavailability of the second MR imaging and 1 for the presence of a missed T12 fracture. This exclusion left a total of 46 patients and 276 disks that were imaged twice. Five patients had  $>2$  MR imaging studies available. For these patients, the data from the first and last available MR imaging study were used. The study group contained 13 men and 33 women, with their ages ranging from 20 to 88 years ( $53.6 \pm 15.2$  years) at the time of the initial study. The mean duration between the 2 MR imaging studies was 31.8 months (range, 4–69 months). In 40 patients, there was more than a 1-year interval between the 2 studies. MR imaging was performed on various 1.5T scanners. A section thickness of 3 mm was used for all studies for both sagittal and axial images with an intersection gap of 0.3 mm.

Sagittal and axial T2-weighted turbo spin-echo images were available for all patients. TR varied between 2650 and 5700 ms. TE ranged from 81 to 120 ms.

## $\kappa$ Analysis

The first step in the use of a new measurement technique is to evaluate its reliability. With techniques that use binary categories or ranks, as ours did, the accepted standard analysis is calculation of  $\kappa$ . Repeat evaluation of the disks for  $\kappa$  analysis revealed almost perfect agreement for signal-intensity grading ( $\kappa$  value of 0.86). Agreement for the presence of annular tears was substantial ( $\kappa$  coefficient, 0.76).  $\kappa$  values for degeneration grade and for annular tear conspicuity were lower (0.57 and 0.55, respectively), corresponding to moderate agreement.<sup>14</sup>

## Results from Initial MR Imaging

On the initial MR imaging, 203/276 disks demonstrated annular tears. Of these, 121 (59.6%) were graded 3 on the conspicuity scale. Grades 2 (22.6%) and 4 (11.7%) accounted for almost all the remaining tears. Only 1 grade 1 tear was found. The frequency of annular tears increased toward the caudal portions of the spine. Whereas 26/46 (56.5%) disks at the T12-L1 level were free of any annular tears, a vast majority (44/46, 95.6%) demonstrated annular tears at both the L4–5 and L5-S1 levels. At the L1–2, L2–3, and L3–4 levels, annular tears were observed in 28/46 (60.8%), 31/46 (67.4%), and 36/46 (78.2%) disks, respectively.

The mean signal-intensity grade for disks with annular tears was noted to be  $3.07 \pm 1.31$ , which was significantly higher than the corresponding value of  $1.43 \pm 0.62$  for disks without annular tears ( $P < .0001$ , Tables 1 and 2). Statistically significant differences were also observed in these 2 groups for degeneration grades ( $P < .0001$ ). Mean signal-intensity and

**Table 3: Distribution of signal-intensity grades and annular tears on initial MR imaging**

	Signal-Intensity Grade					
	1	2	3	4	5	6
Disks with no annular tears ( <i>n</i> = 73)	45 (61.64%)	25 (34.25%)	2 (2.74%)	1 (1.37%)	0 (0.00%)	0 (0.00%)
Disks with annular tears ( <i>n</i> = 203)	21 (10.34%)	61 (30.05%)	44 (21.67%)	38 (18.72%)	37 (18.23%)	2 (0.99%)
	66	86	46	39	37	2

**Table 4: Distribution of degeneration grades and annular tears on initial MR imaging**

	Degeneration Grade				
	1	2	3	4	5
Disks with no annular tears ( <i>n</i> = 73)	0 (0.00%)	58 (79.45%)	15 (20.54%)	0 (0.00%)	0 (0.00%)
Disks with annular tears ( <i>n</i> = 203)	0 (0.00%)	45 (22.17%)	90 (44.22%)	42 (20.69%)	26 (12.81%)
	0	103	105	42	26

degeneration grades were higher for the caudal segments of the spine ( $P = .003$  and  $0.002$ , respectively). Disks without and with annular tears maintained statistically significant differences in their signal-intensity and degeneration grades when analyzed separately for each segmental level. These differences were also present for all grades of tears when analyzed separately.

A vast majority of disks without annular tears demonstrated relatively preserved signal intensity, with almost 96% of such disks showing a signal-intensity grade of  $\leq 2$ . Only 3 such disks demonstrated a signal-intensity grade of  $\geq 3$  (Table 3). Although disks with annular tears were associated with higher signal-intensity and degeneration grades, almost 40% of all annular tears were observed in disks with a signal-intensity grade of  $\leq 2$ . Ten percent of all tears occurred in disks without any loss of signal intensity. There were 66 (23.9%) disks with preserved signal intensity of the nucleus (grade 1 on signal-intensity grade). Disks from upper segments of the lumbar spine constituted most of these disks with T12-L1, L1-2, and L2-3 levels contributing 17, 16, and 12 disks, respectively, to this group. The corresponding number for L3-4, L4-5, and L5-S1 levels was 8, 6, and 7, respectively. Of these disks with preserved nuclear signal intensity, 21 (31.8%) showed annular tears.

Similar trends were also observed with the degeneration grades, with none of the disks with a degeneration grade of  $\geq 4$  showing a preserved anulus (Table 4). In contrast, 22% of all tears were seen in disks with a degeneration grade of 2.

### Change on Sequential MR Imaging

Intervertebral disks with annular tears demonstrated an increase of  $0.42 \pm 0.85$  in the signal-intensity grade on the follow-up study, compared with a change of  $0.15 \pm 0.54$  for the disks without annular tears ( $P < .0001$ ; Tables 1 and 2 and Fig 2). Similarly, disks with annular tears were associated with a significantly higher increase in the degeneration grade, compared with disks without annular tears ( $P < .0001$ ). A similar trend was observed for all individual segmental levels except L4-5. The duration between the 2 MR imaging studies was comparable for these 2 groups (Table 2).

There were 45 disks without annular tears or loss of signal intensity on the initial MR imaging. On follow-up MR imaging, 15 new tears were observed in these disks, 5 of which occurred in the absence of any associated change in the signal-intensity grade. Ten of these tears were accompanied by a

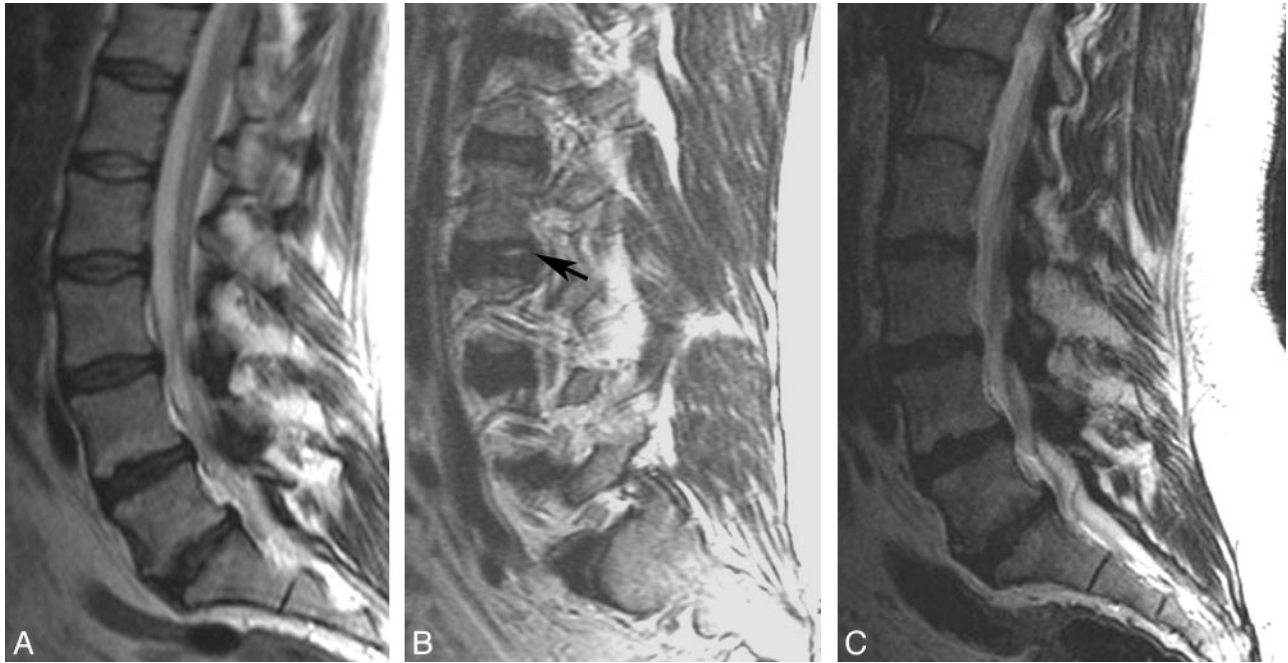
change in the signal-intensity grade of the disks. The grade changed by 1 point in 7, by 2 points in 2, and by 3 points in 1. In addition, 4 disks showed an increase in signal-intensity grade (by 1 point in all) in the absence of an annular tear on the follow-up MR imaging.

### Discussion

#### Association of Annular Tears with Nuclear Degeneration

By showing significantly higher signal-intensity and degeneration grades in disks with annular tears, our results again demonstrate a strong association between MR imaging—demonstrable annular tears and nuclear degeneration, as has been previously noted.<sup>1,2,15</sup> The relative distribution of signal-intensity and degeneration grades in disks without and with annular tears in our study seems to support our first hypothesis that annular tears precede nuclear degeneration. We found a relatively common occurrence of annular tears in the absence of imaging changes usually associated with nuclear degeneration. Ten percent of all tears were observed in disks without any loss of signal intensity, and almost 40% of tears involved disks with signal-intensity grades of  $\leq 2$ . In fact, 30% of all disks with a signal-intensity grade of 1 demonstrated annular tears.

In contrast, it was rare to find disks with more advanced nuclear degeneration in the absence of annular tears. Direct observation of initially normal disks on follow-up MR imaging, however, could not prove this hypothesis conclusively. The appearance of new annular tears was noted on follow-up examination in 33% of initially normal disks. Of these tears, one third occurred without any change in signal-intensity grade. This would support the notion that annular tears precede nuclear degeneration. However, the fact that 4 of the initially normal disks demonstrated a change in the signal-intensity grade in the absence of annular tears contradicts this hypothesis. At the same time, it is noteworthy that within this subgroup of initially normal disks, all 3 disks demonstrating a change of 2 points or higher in the signal-intensity grade were accompanied by the appearance of new annular tears. The change in signal-intensity grade in the absence of annular tears was by 1 point in all 4 disks. It is possible that in some of these disks, this could be related to intraobserver variation rather than representing a true change. It is also possible that 1 or more of these disks developed an annular tear that was not



**Fig 2.** Natural progression of disk degeneration of the L2–3 intervertebral disk during a 24-month period. *A*, The L2–3 disk shows grade 2 signal intensity and grade 2 degeneration on the sagittal T2-weighted turbo spin-echo image from the initial lumbar spine MR imaging. *B*, A right foraminal and extraforaminal grade 2 annular tear is noted at the L2–3 level (*arrow*). *C*, Follow-up MR imaging performed 24 months later demonstrates interval loss of signal intensity and disk height at the L2–3 level, which was graded 4 on both signal-intensity and degeneration scales. Note the relative stability of the L1–2 disk on 2 MR imaging examinations.

apparent. At any rate, annular tears were present in almost 80% (15/19) of disks with new abnormalities.

Some studies have demonstrated the presence of biochemical changes in the nucleus occurring at a relatively young age, leading investigators to hypothesize that degenerative changes in the nucleus precede the annular tears.<sup>3,16</sup> At the same time, a high frequency of annular tears, particularly the radial tears in the setting of disk degeneration, has resulted in the opinion that somehow the annular tears may be linked with the process of nuclear degeneration.<sup>2,5</sup> This view is certainly supported by the animal models demonstrating the causative effects of artificially created annular tears in the subsequent appearance of nuclear degeneration.<sup>17–19</sup> Whether the appearance of annular tears is a harbinger of future degeneration remains unclear. However, our results indicate that annular tears are probably one of the earlier imaging manifestations of the degenerative process affecting the intervertebral disks, and their presence is associated with a more rapid appearance of nuclear degeneration in subsequent imaging studies.

As expected, we found an increasing prevalence of degenerative changes along the lower segments of the lumbar spine. This somewhat limited the evaluation in the lower lumbar spine, due to the very small number of disks without annular tears (2 each at L4–5 and L5–S1 levels). However, the association of annular tears with the loss of signal intensity of disks and overall disk degeneration remained significant, even when analyzed by individual segmental levels.

#### **Temporal Evolution of Nuclear Degeneration**

The results confirm our second hypothesis, with annular tears being associated with more pronounced signal-intensity loss on T2-weighted MR images and degeneration on the follow-up MR imaging. To the best of our knowledge, none of the

prior studies has tried to assess whether the temporal evolution of nuclear degeneration is associated with the presence of annular tears. In our study, disks without annular tears or other signs of degeneration on MR imaging served as controls. Because these controls and disks with annular tears were both obtained from the same group of patients, they were comparable with the overtly degenerated disks in terms of factors such as age, sex, genetic influences, duration between the studies, diet, smoking, occupation, and other environmental variables, which can otherwise be difficult to control.

As is evident from Tables 1, 3, and 4, disks without annular tears demonstrated relatively preserved signal intensity of the central portion of the disk and demonstrated a relatively stable appearance on follow-up with a change of only 0.15 in mean signal-intensity and degeneration grades between the 2 MR imaging examinations. Due to a large prevalence of morphologically abnormal disks in the asymptomatic population, a debate in the literature has considered what constitutes a pathologic degeneration of the disk relative to a normal aging process.<sup>16,20</sup> Our findings support the view that an obvious change in the signal intensity of the disk probably represents a pathologic degenerative process rather than a normal aging phenomenon.<sup>20</sup>

#### **Disk Degeneration and MR Imaging**

We used MR imaging to assess the annular integrity and the nuclear degeneration, because of its noninvasive nature and its ability to show many facets of disk degeneration.<sup>2,21,22</sup> A number of studies have demonstrated the ability of MR imaging in the detection of annular tears.<sup>1,2,23–30</sup> It detects annular tears with a fairly high sensitivity of approximately 67% and a specificity of nearly 100%.<sup>2,15</sup> Use of MR imaging in grading nuclear degeneration has also been well established in the litera-

ture, with substantial-to-excellent intra- and interobserver agreements for the scale of Pfirrmann et al.<sup>13</sup> Its noninvasive nature makes it ideally suitable to observe the progression of such changes, and it has been used to that effect in many longitudinal studies in the past.<sup>8-10,31-33</sup>

Our choice of not restricting our definition of annular tears to the high-intensity zones defined by Aprill and Bogduk<sup>23</sup> likely accounts for the high prevalence (73.5%) of annular tears in our study. A prevalence of 30.2% has been reported previously in patients with back pain by other investigators who specifically ignored minor signal-intensity variations in the anulus.<sup>24</sup> Careful microscopic evaluation of cadaveric disks, in fact, has shown a prevalence of  $\leq 97\%$  of some types of annular tears at the L4–5 level.<sup>6</sup> It is possible that many of these subtle signal-intensity alterations noted as tears in our study correspond to small areas of mucinous degeneration, sometimes described as annular disorganization rather than tears on histologic studies.<sup>3</sup> Histologic studies have noted such areas of annular disorganization in 98.7% of disks from subjects older than 10 years of age.<sup>3</sup> The significance of these subtle areas of annular pathology is not clear. However, we found that the association of annular pathology with higher grades of signal-intensity loss and disk degeneration was maintained across all grades of annular tear conspicuity, suggesting that these changes cannot be assumed to be insignificant.

The loss of the signal intensity of the central aspect of intervertebral disks on T2-weighted images is frequently seen in the setting of degenerative disk disease and is one of the most frequent changes noted in the longitudinal studies of the intervertebral disks.<sup>10,34</sup> Experimental models of disk degeneration have demonstrated that the loss of signal intensity of the disks accompanies various histologic changes of degeneration within the disk.<sup>35,36</sup> Although it is one of the factors influencing the degeneration grade on the scale suggested by Pfirrmann et al,<sup>13</sup> we chose to evaluate the extent of the loss of T2 signal intensity of the disks in a separate arbitrary scale, hoping that by doing so, we would be able to separate disks with relatively small differences in the extent of nuclear degeneration. Some investigators have used objective calculations of T2 relaxation times in the disks with the objective of gaining a continuous and objective measure of disk degeneration.<sup>37</sup> Our signal-intensity scale allowed us to achieve a similar, though semiquantitative, assessment of the signal intensity of the disks, with fairly high internal consistency. On this scale, a more profound loss of signal intensity (grade 3 or higher) was almost always associated with the presence of annular tears. At the same time, minimal loss of signal intensity (grade 2) was not infrequent among disks without annular tears. This mild loss of signal intensity may reflect fibrous transformation of adult disks, as has been described on histologic analysis.<sup>38</sup>

### Limitations of the Study

The presence of annular tears was not proved with diskography. However, association of annular tears with nuclear degeneration for all levels of annular tear conspicuity suggests that even subtle signal-intensity alterations within the anulus likely represent true pathology.

The neuroradiologists interpreting the scans were assessing various parameters, including signal intensity and annular tears at the same time. This could potentially induce a bias so

that the readers were more likely to assign a higher degeneration grade to disks with annular tears, and they could have been more likely to diagnose an annular tear if the nucleus appeared degenerated. We think that this bias was at least partially countered by the fact that one of the hypotheses being tested was related to accelerated degeneration of disks with annular tears and that the readers were blinded to the results of their assessment of the other (initial or follow-up) studies on a given patient. In addition, the studies were evaluated in a random order. For some patients, the initial MR imaging study was evaluated before the follow-up study, whereas the reverse was true for others.

Due to the retrospective nature of the study, different scanners and scanning parameters were used, which could arguably influence the signal intensity of the disk. We think that this was, to some extent, corrected by the fact that these factors were influencing the disks both with and without annular tears. In addition, our signal-intensity scale took into consideration the extent of loss of signal intensity across the central disk volume rather than the degree of brightness of the signal intensity.

We did not try to differentiate types of annular tears, as other authors have done in the past.<sup>6,30,39</sup> This could potentially influence the results if only some types of tears happen to be associated with nuclear degeneration.

We made no attempt to correlate these changes with clinical symptoms. Although correlation with clinical symptoms is certainly a very important aspect of studying disk degeneration, this study aimed just to observe the natural history of disk degeneration.

A prospective study would certainly help in ascertaining the role of annular tears in disk degeneration with more confidence. Such a study could allow better control over some of the variables, such as scanning parameters. It could also benefit from the use of more continuous means of evaluating disk degeneration, such as T2 relaxation times and T1- $\rho$  measurements, which have recently been described.<sup>37,40</sup> At the same time, given the relative stability of the disk appearance for a long period of time, carrying out such a study would certainly prove difficult.

### Conclusions

Our results suggest that MR imaging—demonstrable annular tears appear during the early stages of disk degeneration and are often seen in the absence of other identifiable morphologic changes of degeneration in the nucleus pulposus. Disks with annular tears are also likely to show a greater degree of nuclear degeneration and loss of signal intensity on T2-weighted images on follow-up studies.

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