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Tears of the Anulus Fibrosus: Correlation Between MR and Pathologic Findings in Cadavers

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Tears of the anulus fibrosus, which have been implicated in back pain, have not been studied systematically with MR imaging. We correlated MR images with cryomicrotome sections to study the lumbar anulus fibrosus in 20 cadavers. Three distinct types of tears of the anulus were identified: concentric tears, characterized by fluid-filled spaces between adjacent lamellae; radial tears, characterized by a rupture of all layers in the anulus between the nucleus and the surface of the disk; and transverse tears, characterized by a rupture of Sharpey's fibers in the periphery of the anulus, near the ring apophysis. In each type, fluid or mucoid material was present in the tear. MR demonstrated the transverse and radial tears.

We conclude that MR imaging provides an accurate means for investigating tears of the anulus.

Degenerated intervertebral disks are characterized by tears or ruptures of the anulus fibrosus. Three distinct types of anular tears have been described [1–6]. One type, which Hirsch and Schajowicz [1] called concentric tears, are crescentic or oval cavities filled with fluid or mucoid material between lamellae of the anulus fibrosus. These cavities are associated with rupture of the short transverse fibers connecting the lamellae in the anulus fibrosus without disrupting the longitudinal fibers within the adjacent lamellae. Concentric tears are either solitary or clustered mucoid collections between lamellae. The second type of tear, which Hirsch and Schajowicz [1] also described, is the radial tear, which refers to a fissure extending from the surface of the anulus to the nucleus. The central end of the radial fissure usually connects with a fissure in the nucleus pulposus. Longitudinal fibers in each layer of the anulus fibrosus are disrupted in this type of tear. A third type, the transverse tear, was illustrated by Schmorl and Junghans [2] and by Resnick and Niwayama [3]. Transverse tears are irregular fluid-filled cavities in Sharpey's fibers near their attachments with the ring apophysis. In a sagittal section they have a longer anteroposterior than superoinferior diameter. They result from an interruption of the Sharpey's fibers. This third type of tear has not been studied extensively.

A description of the types of anular tears for the radiologic literature is appropriate because MR imaging or CT may provide the means of demonstrating these tears, which have hitherto been revealed only in anatomic sections or diskograms. If the tears can be imaged radiologically, they can be studied clinically. In reviewing the literature on anular tears we found that the published information was fragmentary. Therefore, we studied disk anatomy systematically in cadavers to determine the frequency of the three types of tears in the anulus and to analyze their MR appearance.

Materials and Methods

Cadavers of a newborn and 19 other subjects, ages 10–86 years, were selected for this study. The ages and genders of the cadavers are given in Table 1. There were 11 females

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TABLE 1: Age and Gender of 20 Cadavers Studied

Age	No. of Cadavers	Age of Cadaver	
		Male	Female
0–9	1	Newborn	—
10–19	2	10, 19	—
20–29	—	—	—
30–39	1	—	37
40–49	3	46	44, 48
50–59	4	53, 58	50, 52
60–69	6	64, 61	60, 63 64, 69
70 and over	3	86	73, 76

and nine males. Seventeen of the cadavers were fresh, acquired for MR within 48 hr of death. Three cadavers had been embalmed prior to imaging and sectioning. The cadavers were imaged on a GE Signa 1.5-T imager. A 4-in. butterfly surface coil* placed behind the lumbar spine received the RF signal. Sagittal plane images sometimes supplemented with coronal or axial images were obtained. Spin-echo sequences with TR/TE of 600/20, 600/40, 2500/20, 2500/60 were obtained. Technical factors included a 256 × 256 matrix and a 3-mm slice thickness. Immediately after MR was completed the cadaver was placed in a freezer at −70°C for at least three days. CT was performed on the frozen cadavers, but the CT scans were not analyzed for this report. A block of tissue that contained the lumbar spine was removed with an electric bandsaw and placed on the stage of an LKB 2250 sledge heavy-duty cryomicrotome. The block was sectioned in the plane of the sagittal images. Five disks were sectioned axially. Photographs of the cut surface were obtained at every millimeter of sectioning. The photographs, especially of sections near the mid-sagittal plane, and the cut surfaces of the specimen were analyzed for evidence of tears of the anulus.

The tears were classified on the basis of their appearance on cryotome sections. A region of fluid or mucoid material in the anulus between lamellae in which the long anular fibers appeared intact were called type-I or concentric tears. Tears were classified as radial or type II if a fluid- or mucoid-filled space was evident in an area extending from the surface of the anulus to the nucleus, with fibers in each layer of the anulus disrupted. The tears were called transverse or type III if torn Sharpey's fibers were evident with fluid or mucoid material filling the hiatus in longitudinal fibers. MR sections were analyzed to determine the MR appearance of the three types of tears.

Results

Most tears in the anulus could be classified easily as type I, II, or III. Focal discoloration of the anulus without a tear was in some cases difficult to distinguish from a small type-I tear. The radial tears had a varied appearance. In most cases, a small defect was evident in the anulus extending from the periphery of the disk to the nucleus. These were called type IIA. In seven disks the anulus appeared to have lost all of its fibrous structure. These were classified as type IIB.

Type-I ruptures were common (Fig. 1). They were found in about 30% of the intervertebral disks, excluding the one found in a 37-year-old woman (Table 2). There was rarely more than one type-I tear per intervertebral disk. The highest incidence of these tears was at the L3–L4 and L4–L5 levels (Table 3). They were found with a slightly higher frequency in the anterior half of the intervertebral disk than in the posterior half (Table 4). They were not effectively demonstrated in the MR images.

The type-IIA tears were slightly less common than the type-I tears (Fig. 2A). They were evident in 21–35% of disks in cadavers over age 40 (Table 2). In cadavers under age 40 they were rare, usually not more than one per disk. The greatest number of type-IIA tears appeared at the L4–L5 and L5–S1 levels (Table 3). They were more common in the posterior aspect of the intervertebral disk than in the anterior aspect (Table 4). In long TR, long TE MR images, they appeared as a region of increased signal, which corresponded in shape and location to the tear (Fig. 2B). They were not effectively demonstrated in T1-weighted spin-echo images. Most type-IIB tears were seen in cadavers over age 70; but one was in a 37-year-old woman (Fig. 3A) (Table 2). Type-IIB tears could be seen at each level, but more commonly at the L4–L5 and L5–S1 levels (Table 3). Large osteophytes and greatly diminished disk height were commonly associated with type-IIB tears. In MR images the fluid- or mucoid-filled disk spaces had a strong signal intensity, similar to that of the CSF (Fig. 3B).

Type-III tears were the most common (Fig. 4A); often with more than one per disk. They were seen in 27–61% of the disks in cadavers over age 37 (Table 2). They were found at all levels but especially at L1–L2, L2–L3, and L3–L4 (Table 3). They were more common in the anterior aspect of the disk than in the posterior aspect (Table 4). In long TR, long TE MR images they appeared as a region of increased signal intensity corresponding in shape and location to the liquid collection seen in cryomicrotome sections (Fig. 4B).

Discussion

Cadaver studies of degenerative changes in intervertebral disk space have limitations. The ages and genders of cadavers usually do not correspond to the ages and genders of patients scanned for suspected intervertebral disk disease. The cadavers in our study comprised a higher proportion of females and septagenarians than found in our usual patient population; nonetheless, our study included cadavers in nearly all decades of life. The degenerative changes detected in cadavers usually represent end stage, healed processes rather than active, symptomatic processes found in live subjects. To obtain material for studying acute degenerative changes in the disk, animal models must be used. And the number of cadavers that can be studied by the time-consuming cryotome technique is small. Another limitation of cadaver studies is the artifacts found in anatomic sections that result from freezing [7] and those seen in MR images that result from postmortem changes and subnormal temperatures. In our study the appearance of tears in MR images obtained before freezing correlated well with the appearance of tears in images obtained after freezing.

Our results with type-I tears agree in many respects with those of Hirsch and Schajowicz [1], who, like us, found type-I tears to be relatively common. These authors found them

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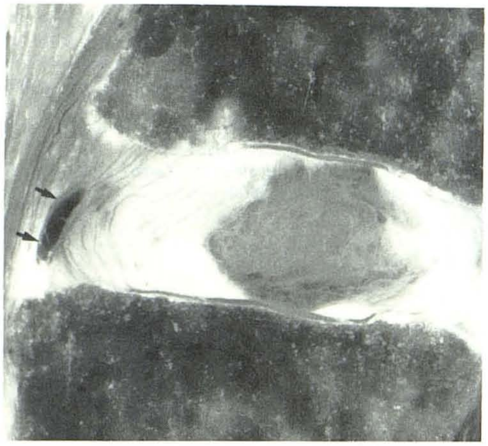
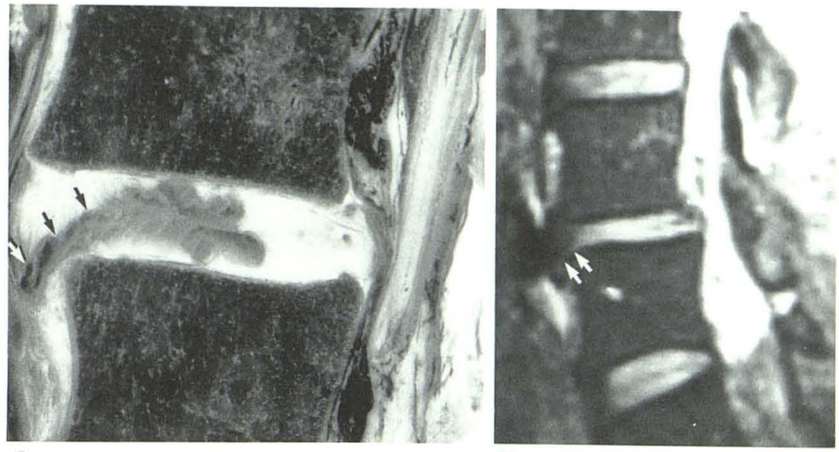


Fig. 1.—Sagittal cryomicrotome section showing type-I tear in anulus fibrosus (*arrows*). Anular fibers are intact. Tear is within anterior Sharpey's fibers.



A B

Fig. 2.—Cryomicrotome section (*A*) and T2-weighted MR image (*B*) illustrate type-II radial tear (*arrows*) in anterior anulus fibrosus. Tear extends to anterior surface of disk and to nucleus pulposus. In MR image, fluid-filled space in Sharpey's fibers appears as bright signal replacing normal low-intensity signal, as seen in disks above and below.

TABLE 2: Disks with Anular Tears, by Age (n = 98)

Age	No. of Cadavers	Type I[a]	Type IIA[a]	Type IIB[a]	Type III[a]
0–9	1	0	0	0	0
10–19	2	30	10	0	10
20–29	0	—	—	—	—
30–39	1	0	0	20	40
40–49	3	27	27	0	53
50–59	4	45	35	0	50
60–69	6	32	21	7	61
70 and over	3	47	33	27	27

[a] Percentage of disks with anular tears to number of disks.

TABLE 3: Disks with Anular Tears, by Disk Level (n = 98)

Level	No. of Disks	Type I[a]	Type IIA[a]	Type IIB[a]	Type III[a]
L1–L2	19	11	5	5	42
L2–L3	19	21	11	5	58
L3–L4	20	55	10	5	60
L4–L5	20	50	55	10	35
L5–S1	20	25	35	10	20

[a] Percentage of disks with anular tears to number of disks.

TABLE 4: Frequency of Anular Tears in Anterior and Posterior Disks (n = 98)

	Anterior (%)	Posterior (%)
Type I	20	12
Type IIA	8	18
Type III	44	10

more often in the posterior disk, whereas we found them more often in the anterior disk. They did not mention at which levels they occurred. They noticed no type-I tears in cadavers younger than age 15, whereas we found some in a 10-year-old cadaver.

Type-II tears have been illustrated previously [1, 2]. Hirsch and Schajowicz described their appearance in cadavers. Fernstrom [8], who called them simple disk rupture to distinguish them from a herniated nucleus pulposus [8], used cadaver studies to describe how their diskographic appearance resembled that of a herniated disk.

Information on type-III tears is fragmentary. Hirsch and Schajowicz [1] did not mention type-III tears. Presumably, the axial sections they used to study intervertebral disks do not effectively demonstrate the tears. Schmorl and Junghans [2] illustrated them. Resnick and Niwayama [3] and Peacock [5] observed type-III tears in sagittal anatomic specimens. Gas within the anulus in a presumed type-III tear has also been reported [3, 9–11]. We know of no other mention of type-III tears.

The clinical significance of these tears cannot be studied effectively in cadaver material. According to Hirsch and Schajowicz [1], type-I tears have no clinical significance because no nerve endings penetrate the disk. Therefore, the rupture of the small fibers between lamellae that results in type-I tears would not be a painful process. Type-II tears, on the other hand, have been thought to be clinically significant. Fernstrom [8] showed that radial tears could be detected diskographically, and described 35 patients with abdominal, pelvic, or lumbar pain presumably resulting from the presence of surgically verified radial tears. Cloward [12] described "discogenic pain" secondary to radial tears and developed the interbody fusion procedure for treating these patients. Fernstrom [8] agreed with the surgical treatment of radial tears, stating that "surgical treatment of simple disc rupture [type-II tears] shows that this type of degenerated disc may provoke

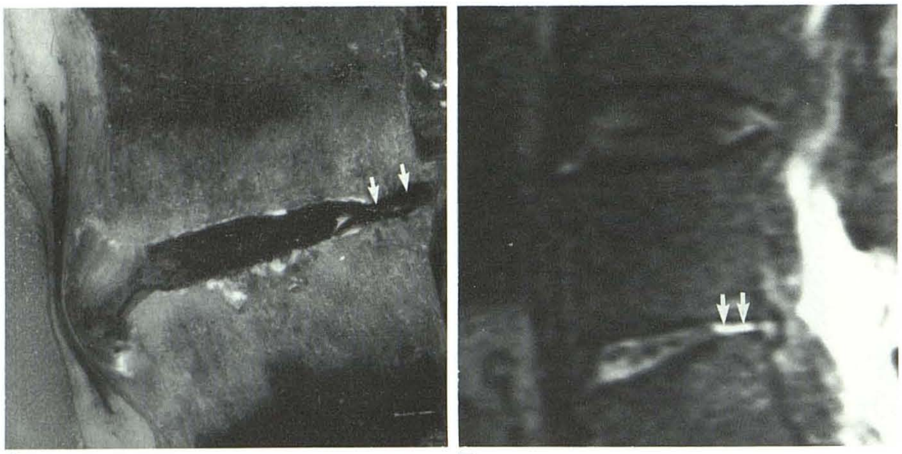


Fig. 3.—Cryomicrotome section (*A*) and MR image (*B*) in type-IIB tear of anulus at L4–L5. At L3–L4, type-I and type-III tears are seen better in anatomic section, and less effectively in MR images.

***A*, Fibrocartilaginous structure of disk is completely disintegrated (*arrows*).**

***B*, Tear has bright signal (*arrows*) in this T2-weighted image (2500/80).**

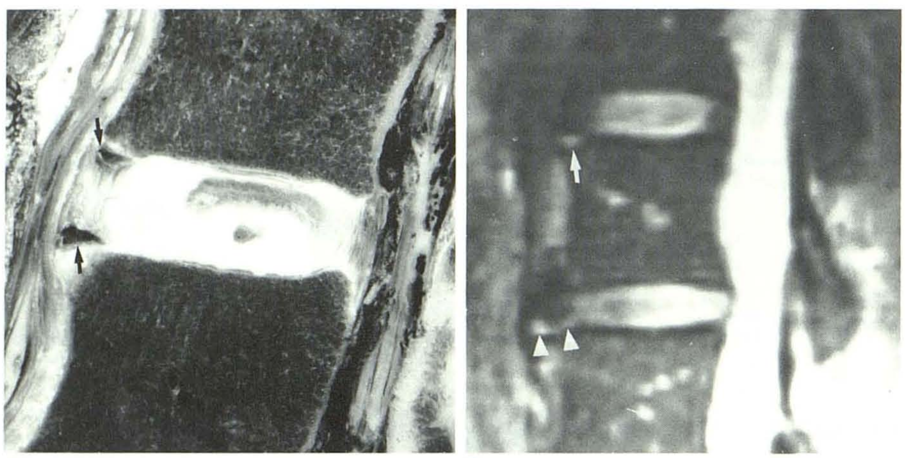


Fig. 4.—Cryomicrotome section (*A*) and T2-weighted MR image (*B*) of L3–L4 intervertebral disk show two type-III tears (*arrows* in *A*) in anterior anulus fibrosus. One of the tears was shown by MR as a high-intensity signal (*arrow* in *B*). Type-II tear is present in L4–L5 disk (*arrowheads*).

pain." The mechanism of pain from radial tears is not certain [13], but one study [1] implicated nerves that grow into radial tears along with blood vessels and granulation tissue during the healing process. On the other hand, Kieffer et al. [14] observed that the high incidence of radial tears in cadavers suggested that they were incidental and not clinically significant findings. Type-III tears, which are more common than type-II tears, are not thought to be vascularized, innervated, or significant.

These common but relatively unfamiliar types of anular degeneration should be studied. With optimized techniques, MR or CT might represent effective tools for studying these tears clinically.

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