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An Experimental Model to Study Contrast Enhancement in MR Imaging of the Intervertebral Disk

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MR imaging after IV gadolinium-DTPA administration has demonstrated contrast enhancement in traumatized lumbar intervertebral disks. To characterize the morbid anatomy that correlates with the contrast enhancement, we developed a canine model of traumatized intervertebral disks. Diskectomy was performed with a nucleotome and the spines were imaged biweekly with MR and Gd-DTPA. The spines were studied at necropsy, and their anatomic abnormalities correlated with contrast enhancement detected by MR imaging.

Our preliminary results indicate that contrast enhancement occurs where granulation tissue develops in traumatized intervertebral disks.

Portions of lumbar disks subjected previously to diskectomy have been observed to enhance in MR imaging; that is, to increase in signal intensity after an IV administration of Gd-DTPA (Fig. 1) [1]. No contrast enhancement has been observed in normal intervertebral disks with CT or MR, except possibly in the anterior longitudinal ligament and extreme periphery of the anulus fibrosus [2, 3]. To obtain radiologic/pathologic correlation in disks with contrast enhancement, we produced a model of traumatized disks in mongrel dogs. Results in two animals are described in this preliminary report. The model may be used to study the rate of occurrence of contrast enhancement in disks, its relationship to diskectomy, and some of its clinical manifestations.

Materials and Methods

Two mongrel dogs, weighing 25–30 kg, were subjected to nucleotome instrumentation of the disk. The technique for nucleotome extraction has been described elsewhere in detail [4]. The dogs were anesthetized with pentabarbitol (25 mg/kg IV) and the skin was prepared for a posterolateral approach to the L4–L5 and L5–L6 disks. The trochar supplied with the nucleotome was placed into the nucleus pulposus of L4–L5 under fluoroscopic monitoring. A dilator and cannula were advanced around the trocar to the anulus fibrosus. The dilator was then removed and replaced with a trefine, which was rotated and advanced 3 mm to disrupt the anulus and then it was replaced with the dilator. The dilator and cannula were advanced 3 mm into the outer anulus. The trochar and dilator were removed and the nucleotome probe was placed through the cannula into the nucleus pulposus. The nucleotome was operated at high cutting rate and maximal suction for 10 min or until disk material was no longer extracted from the nucleus pulposus. The nucleotome probe was removed and the procedure was repeated at L5–L6. The dogs were observed in a recovery room after the experimental procedure, then returned to their kennels and not restricted or medicated.

Before diskectomy and approximately biweekly thereafter, MR images were obtained of the dogs' lumbar spines. For imaging, the dogs were anesthetized with pentabarbitol and placed in a 1.5-T G.E. imager with a 3-in. surface coil for the RF receiver. A short TR sequence with 800/20/2 (TR/TE/excitations), 256 × 256 matrix, and 5-mm slice thickness and a long TR sequence (2500/70) were obtained. IV Gd-DTPA 0.4 mmol/kg was then administered, and the short TR images repeated. The pre- and post-Gd-DTPA short TR images were compared for evidence of contrast enhancement in the disk. The long TR

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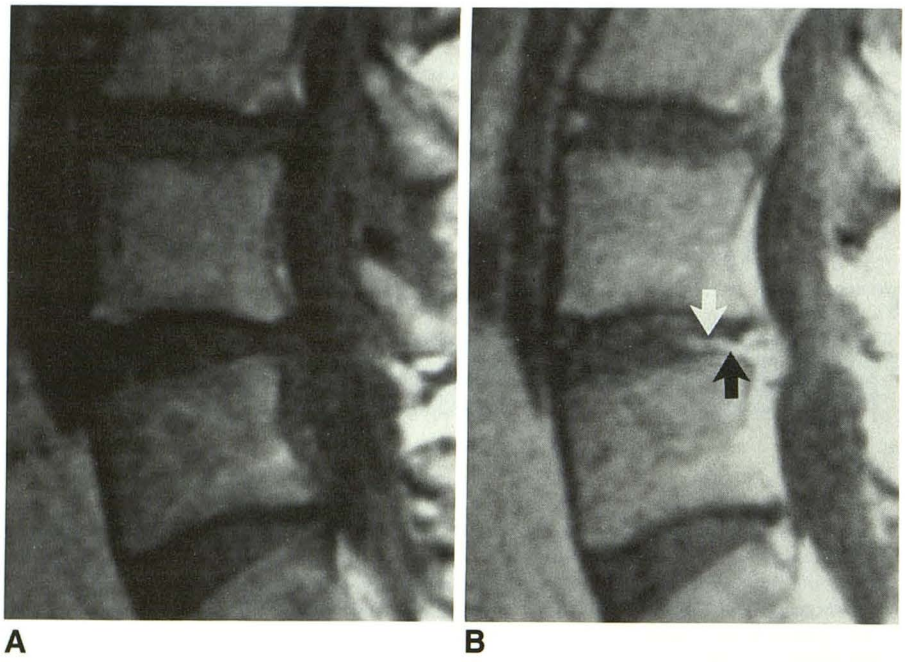

Fig. 1.—Contrast-enhanced MR images of lumbar intervertebral disk in 51-year-old woman 8 months after laminectomy and diskectomy.

***A*, Sagittal image (800/20) of lower lumbar spine shows relatively homogeneous low signal intensity in L4–L5 disk.**

***B*, Repeat short image (800/20) after administration of Gd-DTPA shows increase in signal intensity in posterior margin of disk and in a linear region deep within disk (*arrows*).**

images were also assessed for evidence of abnormal signal intensity from within the disks.

The dogs were necropsied 6 weeks after the nucleotome procedure. The cadaver was frozen and the spine sectioned with a sledge cryomicrotome, and sections recorded photographically [5, 6]. After the spine was sectioned to the midline with the cryomicrotome, the remaining half of the spine was removed from the cryomicrotome, fixed in formalin, embedded, sectioned, stained with hematoxylin and eosin as well as other stains, and examined microscopically. The photographs displaying the sagittal anatomic sections of the dog and the MR images that exactly corresponded were compared.

Results

Four diskectomies were performed in the two dogs. No adverse effects of the nucleotome procedures on the activities of the dogs were observed.

Contrast enhancement was observed in three of the treated intervertebral disks. It was detected first at 2 weeks in one dog, at 3 weeks in the other, and thereafter in both until necropsy. The enhancement appeared less intense at 4 and 6 weeks than at 2 and 3 weeks. The contrast enhancement appeared as a collar-button-shaped region of high signal intensity on the T1-weighted images obtained after Gd-DTPA administration (Figs. 2A and 2B). Enhancement appeared to be greatest near the vertebral endplate. The control disks and one of the treated disks showed no enhancement.

On cryomicrotome sections the treated disks were narrowed and discolored. In the three disks that enhanced after Gd-DTPA, numerous small vascular channels penetrating the endplates and posterior anulus were evident (Figs. 2D and 2E). Histologic sections confirmed a defect in the anulus fibrosus filled with an irregular mix of cartilage, fibrous tissue, and blood vessels with no inflammatory cell infiltration. A fourth treated disk, which never showed contrast enhancement, appeared narrowed and less translucent in the cryomicrotome sections (Fig. 2) but contained no blood vessels. Blood vessels and granulation tissue were not noted in the uninstrumented intervertebral disks (Fig. 1).

Discussion

Except in fetuses or newborns, normal human intervertebral disks lack a vascular supply [5, 6]. Movement of metabolites into and out of the intervertebral disk occurs by diffusion or convection through the endplates and anulus [7]. Without a vascular supply, the normal adult intervertebral disk does not enhance with IV contrast material, except possibly near the anterior longitudinal ligaments, which are vascularized [2, 3]. Therefore, the observation of contrast enhancement within the intervertebral disk indicates an important alteration of disk morphology. Our studies show that granulation tissue (fibrous and vascular), which explains the contrast enhancement, fills the traumatic defect in the anulus fibrosus. The development of granulation tissue within the intervertebral disk in experimental studies and probably in clinical practice can be detected with IV Gd-DTPA and MR imaging.

Other investigators have identified blood vessels and granulation tissue in abnormal intervertebral disks [8–14]. Vascularity has been noted in the anulus fibrosus of cadavers over the age of 40 years [8–10]. The vascularity was thought be the result of radial tears of the anulus that are in the process of healing [11]. One investigator suggested the vascularization and granulation represented a mechanism for resorption of disk matrix [12]. Granulation tissue has been observed in degenerating disks in cattle [13] and in dogs [14].

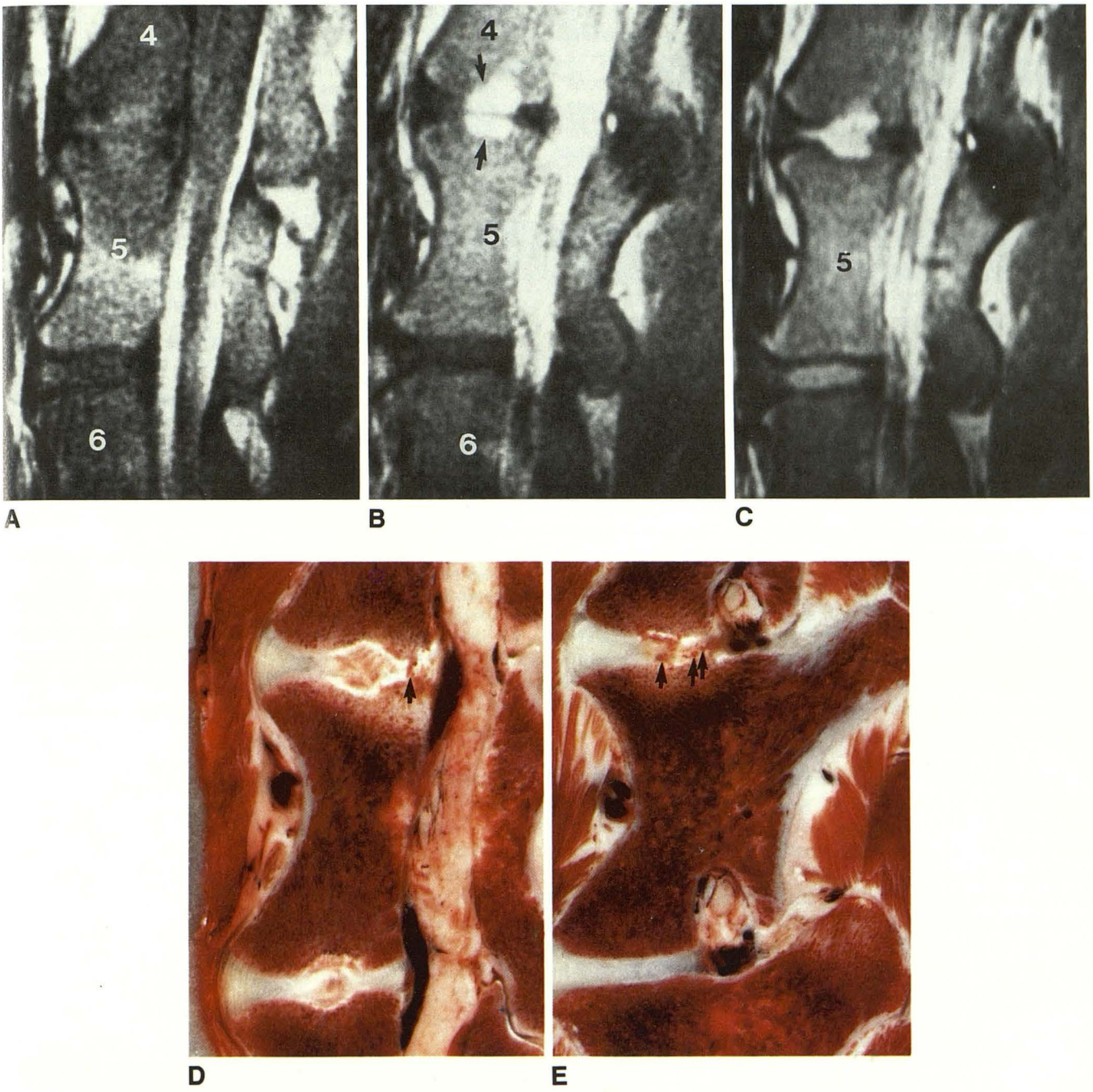

Fig. 2.—MR and cryomicrotome sections demonstrate contrast enhancement in a canine lumbar disk 3 weeks after diskectomy.
***A*, Short TR, short TE image (800/20) prior to administration of Gd-DTPA shows L4–L5 and L5–L6 disks.**
***B*, After IV Gd-DTPA, L4–L5 disk shows contrast enhancement (*arrows*).**
***C*, Long TR, long TE image shows abnormally bright signal from L4–L5 disk.**
***D* and *E*, Parasagittal cryomicrotome sections near midline (*D*) and neural foramen (*E*) show diminished height of both L4–L5 and L5–L6 disks and numerous reddish linear structures (*arrows*), proved histologically to be blood vessels, in the posterior portion of L4–L5 disk. The L6–L7 disk, which had no contrast enhancement, appears normal on the cryomicrotome section.**

The experimental study does not reproduce exactly the conditions in which enhancement was observed clinically in patients with epidural fibrosis and a history of laminectomy. The trauma to the disk and endplate from the experimental nucleotome procedure may not resemble that from surgical curettage in patients with degenerating disks. The contrast enhancement observed clinically in disks is more linear than what we observed experimentally. Signal intensity (on T2-weighted images) from the affected disks evidently was not diminished in the experimental model, as it usually is in degenerating human disks. The difference in signal intensity may be due to the timing of the scan with respect to the injury

of the disk. Contrast enhancement in the disk could have more than one explanation, and may have a different meaning in the dogs than in human patients.

MR provides the opportunity not only to detect herniations of the nucleus pulposus but also to analyze chemical and structural changes within the disk. Studies of structural changes occurring in the lumbar disks are likely to increase the applications and value of MR imaging in low back and sciatic pain.

The percentage of disks that have contrast enhancement after diskectomy has not been reported, since experience with contrast-enhanced MR is limited. Whether contrast enhancement in the disk represents a normal stage of healing or an ineffective repair process is not known. Whether contrast enhancement occurs in disks not previously instrumented is also unknown. Since CT is less sensitive than MR for detecting contrast enhancement (Breger RK, Williams AL, Daniels DL, et al., unpublished data), it has not provided observations on contrast enhancement that can be related to MR. The clinical manifestations, if any, of enhancement in the disk are unknown. The patients in whom we noted contrast enhancement were symptomatic, but causes of pain other than the disk could not be excluded. Since nerves and nerve endings are characteristically present in granulation tissue, such tissue could represent a source of pain. For these reasons, more study is needed in experimental models and in patients to evaluate contrast enhancement in the disk.

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