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Degenerative disk vascularization on MRI: correlation with clinical and histopathologic findings

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Abstract *Objective.* This prospective study was designed to determine the MRI features, clinical significance, and correlation to histopathologic findings of secondary vascularized degenerative intervertebral disks.
Materials and methods. Fifty-three patients with localized painful spine syndrome were investigated prospectively by contrast-enhanced MRI. Pain was not predominantly radiating and there was no clinical evidence of spinal infection. In all patients sagittal SE T1-weighted, fast-SE T2-weighted or turbo-STIR, and T1-weighted frequency-selective fat-suppressed images were obtained.
Results. We identified 37 vascularized disks in 26 patients. In 18 patients the changes had occurred spontaneously, in 6, the affected disk had been operated on previously, and 2 patients had spondylolisthesis. In 15 patients, vascularization was accompanied by medullary edema adjacent to the vertebral endplates. In one of the vascularized disks, herniation was also found. In seven patients, ventral diskectomy was performed. Histopathologic findings confirmed disk vascularization in six of seven cases.
Conclusions. Degenerative, band-like disk vascularization is a feature which is associated with local pain. It is demonstrated by contrast-enhanced MRI. Degenerative disk vascularization is an important differential diagnosis to bacterial spondylodiskitis. It can be a cause of pain in patients with postdiskectomy syndrome.

Key words Gd-DTPA · Intervertebral disk, degeneration · Intervertebral disk, vascularity · Magnetic resonance imaging (MRI) · Fat-suppression · Postdiskectomy syndrome

Introduction

Degeneration of intervertebral disks is part of the normal aging process. Spinal radiographs of 70-year-old individuals show reduced height of at least one intervertebral disk space and osteophytic lipping in almost all [1–3]. Dehydration and disintegration of the disk leads to increased segmental mobility. Some cases of intervertebral disk degeneration are accompanied by medullary edema (Modic type I reaction) in the adjacent vertebrae. If this becomes chronic it may lead to fatty degeneration (Modic type II) and sclerosis (Modic type III) of the medullary cavity [4–7].

Patients with chronic, severe localized back pain are usually investigated by computed tomography (CT) and/or MRI in addition to plain films, in order to rule out herniated disks, spinal stenosis, or facet joint disease. These patients may have negative imaging studies apart from degenerative loss of disk height at one or more levels. Flexion and extension studies may fail to demonstrate radiologically evident segmental instability. We found patients suffering from severe localized back pain in whom the only finding on MRI was a band-like enhancement of disk tissue following Gd-DTPA administration. Disk tissue of adult individuals is devoid of vessels and therefore does not exhibit the early contrast en-

hancement related to vascularity [8]. In some patients, however, disk degeneration is followed by ingrowth of vascularized granulation tissue causing secondary vascularization of the disk material [8, 9]. Our study was conducted to describe the clinical, MRI, and histopathologic features of this complication of degenerative disk disease.

Patients and methods

Between May 1993 and August 1994, 53 selected patients were prospectively investigated by contrast-enhanced MRI of the spine. The ages of the patients ranged from 31 to 72 years, with a mean of 52 years. In accordance with the patients' symptoms, 42 lumbar and 11 thoracic examinations were conducted. Clinical evaluation was performed by the orthopetic surgeon (A.K.). The selection criterion was a severe localized painful back syndrome defined by clinical investigation and without predominant sciatic or radiating pain. Major disk herniation was excluded by CT in 45 patients prior to MRI. All patients had biplane spinal radiographs. Ten patients had a history of previous disk surgery, which had been performed 3 months to 15 years previously (mean 5.3 years).

No patient had any clinical or laboratory evidence of bacterial infection. Leukocyte counts and sedimentation rates were within the normal range and none of the patients had fever. Patients with a history of cancer were excluded. No patient had motor, sensory, or other neurological deficits. Clinical and radiological follow-up of all patients was performed after 3–21 months.

In seven patients, the affected disk had been excised and was available for histologic and microbiological examination. Indication for surgery (ventral diskectomy, vertebral fusion, and dorsal internal fixation) was based on radiological and clinical findings and was not influenced by MRI findings. Besides normal H&E staining for visualization of vascularity, immunohistological preparation with antibodies to S-100 protein was performed for detection of neural fibers in the areas of neovascularization.

MRI was performed using a spinal surface coil (FOV 25 cm) at a field strength of 1.0 tesla (Impact; Siemens AG, Erlangen, Germany) or 1.5 tesla (Vision; Siemens AG). Slice thickness was 3–5 mm, matrices applied were 256×256 or 512×300. In all patients sagittal T1-weighted spin-echo (SE) images (TR/TE=550–500/15–17 ms) were acquired before and after administration of Gd-DTPA (0.1 mmol/kg b.w.). Either sagittal fast-SE T2-weighted (TR/TE=4000/40, 112 ms), turbo-STIR (TI/TR/TE= 175/3000/40 ms) or opposed phase gradient-echo (GRE) images (TR/TE/α=500 ms/17 ms/90°) were obtained for T2-weighted image contrast. Forty-two patients were examined with frequency-selective fat-suppressed T1-weighted pulse sequences (TR/TE= 670/15 ms) after Gd-DTPA administration. T1-weighted images were acquired immediately after contrast material injection, frequency-selective T1-weighted images thereafter. Axial images were obtained in accordance with imaging findings but were not included in the study evaluation.

T1-weighted pre- and post-Gd-DTPA thoracic and lumbar spine imaging studies of 34 age-matched control subjects were evaluated retrospectively for enhancement of disk material. These examinations had been performed to rule out or confirm a spinal mass in the presence of neurologic deficits. The patients had no history of chronic, localized back pain; although some patients suffered from back pain to varying degrees, pain was not the reason for the MRI studies. Subsequently, multiple sclerosis (MS) was diagnosed in seven patients, ten patients had intraspinal tumors (astrocytoma, ependymoma, meningioma, schwannoma), five had metastases, and two vertebral hemangiomas. In two patients meningitis carcinomatosa was found and in 15 (including five patients with MS) no pathologic processes were demonstrated.

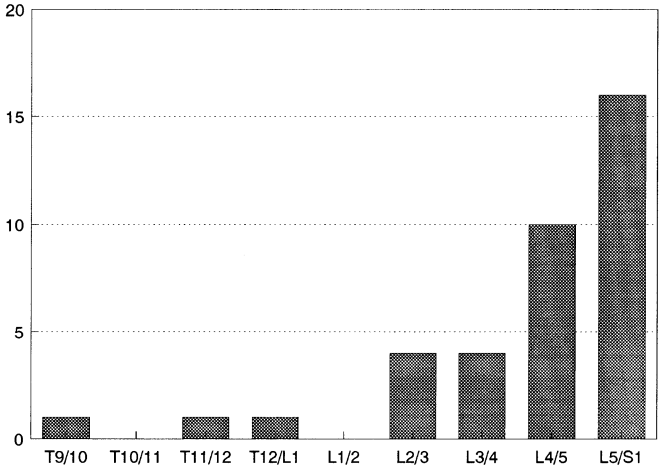


Fig. 1 Location of 37 degenerative vascularized disk segments in 26 patients

Image evaluation was by two musculoskeletal radiologists who reached a consensus diagnosis as to disk enhancement, adjacent bone marrow edema, fatty bone marrow degeneration, disk herniation, spondylolisthesis, spinal stenosis and other pathologic conditions. T1-weighted and fat-suppressed images were rated against each other as equal or superior in demonstrating contrast enhancement. To confirm the subjective image interpretation, the signal intensity of enhancing disks before and after Gd-DTPA administration was measured over regions of interest (ROI). Enhancement was calculated as percentage of signal increase.

Results

MRI showed contrast enhancement in 37 disks in 26 patients (12 male, 14 female). In all patients with more than one enhancing disk (n=8), there was one predominantly affected segment. Only lumbar and lower thoracic segments were involved (Fig. 1). The lumbosacral disk was by far the most frequently affected (16/37), followed by the L4/5 disk (10/37). Six patients exhibited contrast enhancement in two disks, one patient in three disks and, in one other four, disks showed contrast enhancement. Of the 11 additional vascularized disks – i.e., not the predominantly affected disks – 10 showed circumscribed, punctate contrast enhancement in the annulus fibrosus, while one also showed a band of contrast enhancement.

Six patients with enhancing disks had undergone disk surgery prior to the MRI study (failed back surgery syndrome). Disk surgery had been performed 3 months (n=1), 5 months (n=1), and between 2 and 15 years (n=4) prior to MRI. Enhancing disk material was found at the previously operated level in all six patients. Epidural scar tissue was identified in four of these six patients.

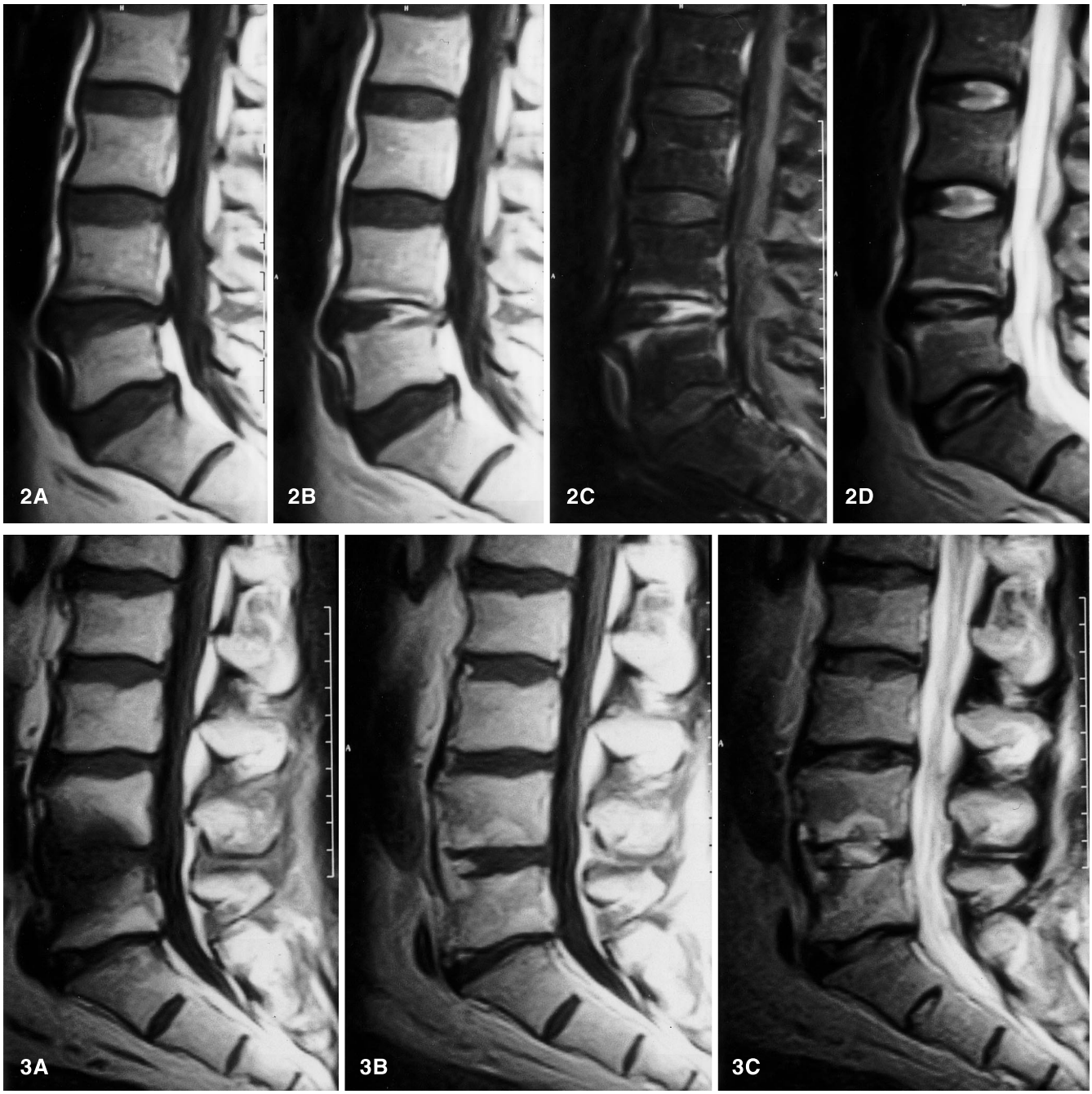
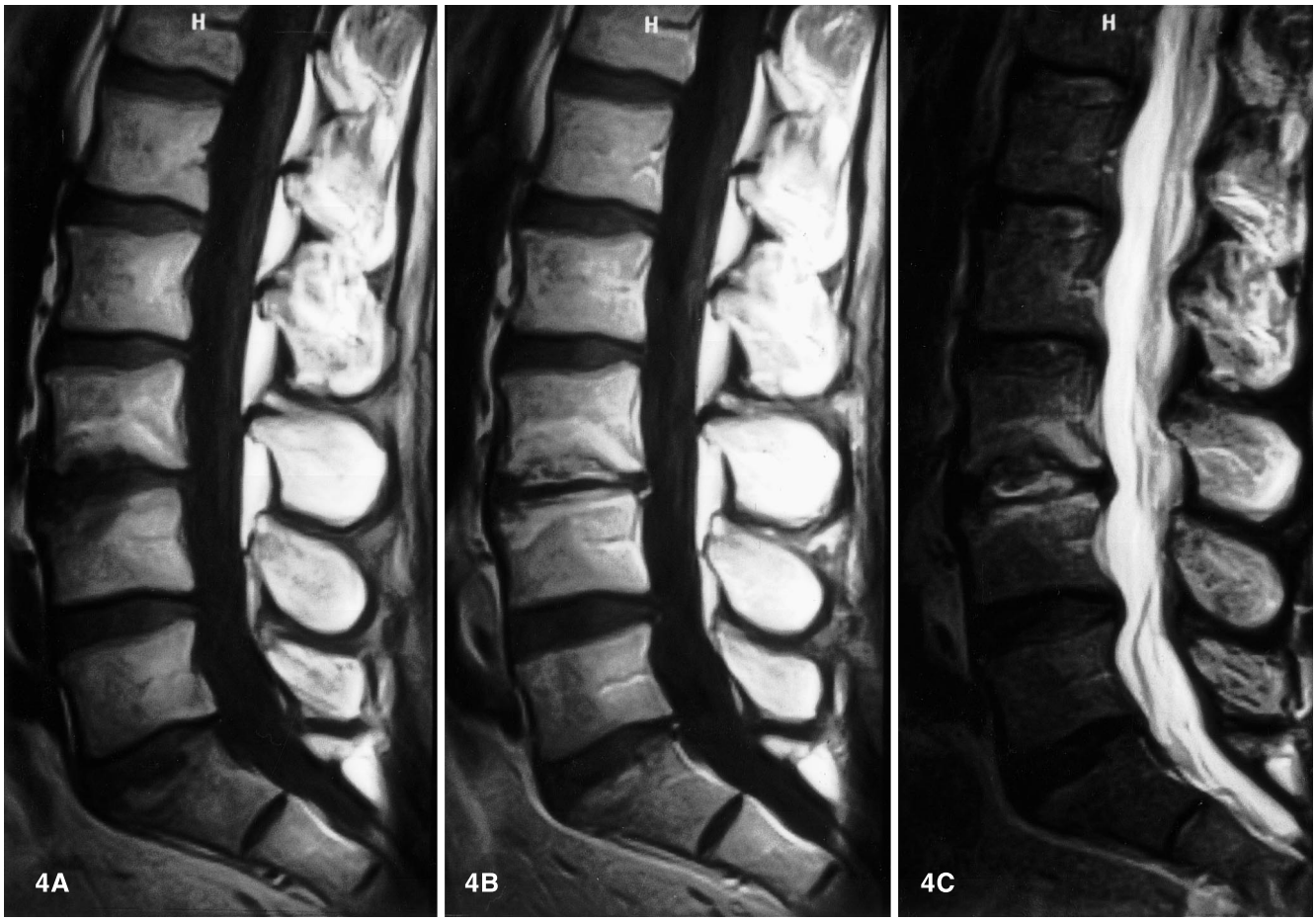


Fig. 2 T1-weighted SE images (500/15 ms) before (**A**) and after contrast administration (**B**). The L4/5 disk is reduced in height and there is anterior and posterior bulging of the annulus fibrosus (**A**). Bands of contrast enhancement along the adjacent vertebral endplates are demonstrated after intravenous injection of Gd-DTPA (**b**), which is shown with high contrast on the T1-weighted frequency-selective fat-suppressed image (670/15 ms; **C**). The L4/5 and L5/S1 disks have reduced signal intensity on the fast-SE T2-weighted image (**D**; 4000/90 ms), indicating degenerative disease. Note also contrast enhancement within the localized bone marrow edema adjacent to the endplates

Fig. 3A–C Patient 3 months after disk operation on L4/5. Bone marrow edema is present adjacent to the endplates of L4/5 (**A**). After intravenous Gd-DTPA administration, the anterior portion of the annulus fibrosus of the L4/5, L2/3, L3/4, and L5/S1 disks and the posterior part of the annulus of the L2/3 disk exhibit definite enhancement (**B**). Although the most affected disk, L4/5, has increased signal intensity on T2-weighted imaging (**C**), no infection was present. The patient was operated and pain-free immediately after fusion of L4/5 was performed. On histologic examination and culture of the specimen, no organisms were found and no signs of infection were present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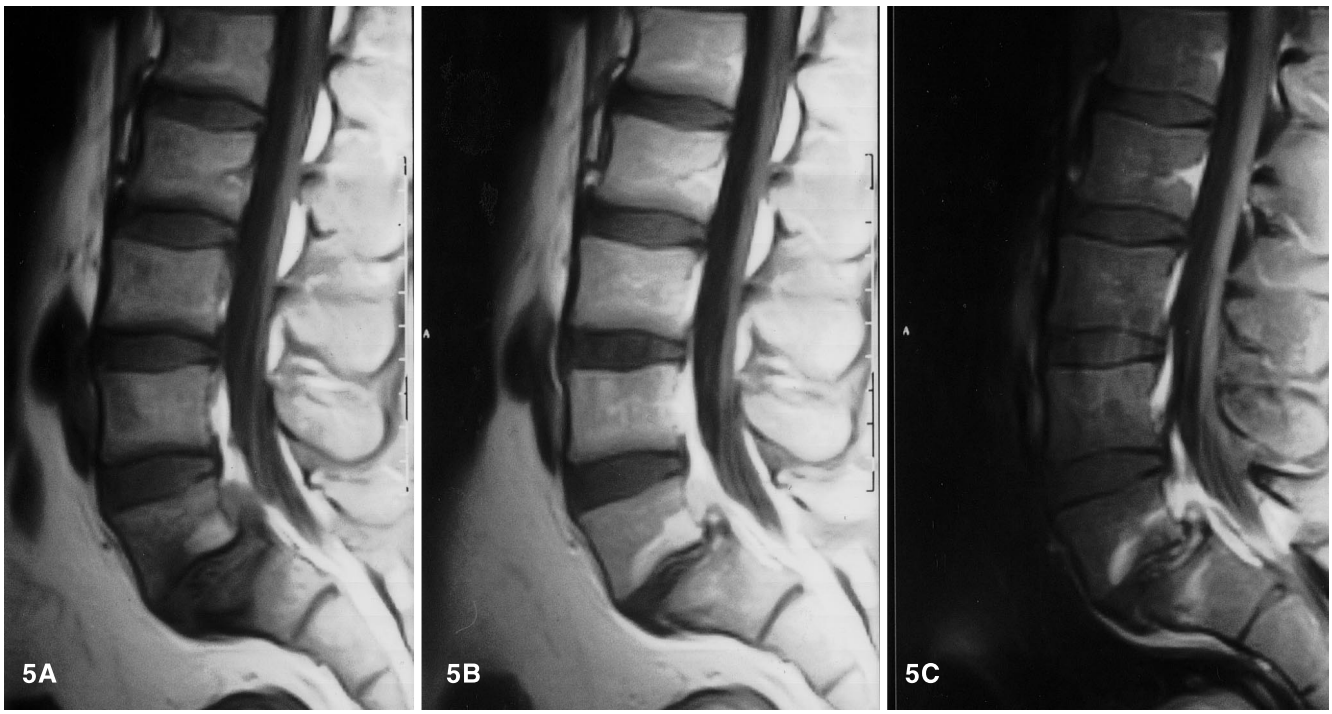
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In 20 patients with enhancing disks, no surgery had been performed previously.

Two patterns of contrast enhancement were found. In 21 of the primarily affected disks, bands of enhancement adjacent to the neighboring vertebral endplates were detected, while the central portion of the disk did not exhibit any enhancement (Fig. 2). All these segments were reduced in height. In five patients only circumscribed (punctate) areas of contrast enhancement confined to the annulus were detected. Secondary involved levels showed this pattern of enhancement (Fig. 3). Contrast material enhancement in vascularized disks was marked, the increase in signal intensity after Gd-DTPA administration ranging from 143% to 277%, with a mean of 192%. Enhancing disks revealed low signal intensity on T2-weighted pulse sequences in five and high signal intensity in three patients.

In 14 patients with enhancing disks, erosions of the adjacent endplates with small cartilaginous herniations into the cancellous bone of the vertebrae were found (Fig. 4). In the rest, no alterations of the endplates were detected. Patients with erosive changes in the endplates were significantly older (mean 55.7 years) than those without (mean 48.2 years, $p<0.05$, *t*-test).

Bone marrow of the vertebral bodies adjacent to the enhancing disks showed signal alterations in 23 of 37 segments. Sixteen segments exhibited areas of decreased signal on T1-weighted images with increased signal intensity on T2-weighted, STIR, or opposed GRE images (bone marrow edema, granulation tissue), eight segments were accompanied by high-signal-intensity bone marrow on T1-weighted images (fatty degeneration). In one case, both decreased and increased signal on T1-weighted imaging was found in the same vertebra (Fig. 5). GRE sequences sensitive to susceptibility effects showed areas of signal loss in seven patients due to bony sclerosis as shown on the conventional films. At the other levels of the patients with enhancing disks, no bone marrow edema was detected, whereas in the remaining 27 patients without enhancing disks five Modic type I reactions were found.

◀ **Fig. 4A–C** Patient with severe local back pain without radiating sciatica. The L3/4 disk is reduced in height and erosions of the endplates are seen (**A**). Following intravenous Gd-DTPA administration, a band-like enhancement in the diskspace and in the vertebral erosions are found (**B**). T2-weighted imaging shows high signal within the degenerated L3/4 disk with signs of aseptic inflammation (**C**)

Fig. 5A–C Spondylolisthesis L5/S1. T1-weighted imaging shows anterior displacement of L5 with disk herniation, rupture of the posterior longitudinal ligament, and fatty degeneration in the posterior part of L5 (**A**). Linear disk enhancement parallel to the posterior parts of the endplates, epidural enhancement, and enhancement of bone marrow edema is seen following intravenous Gd-DTPA administration (**B**). Enhancement is demonstrated with better contrast on frequency-selective fat-suppressed imaging (**C**)

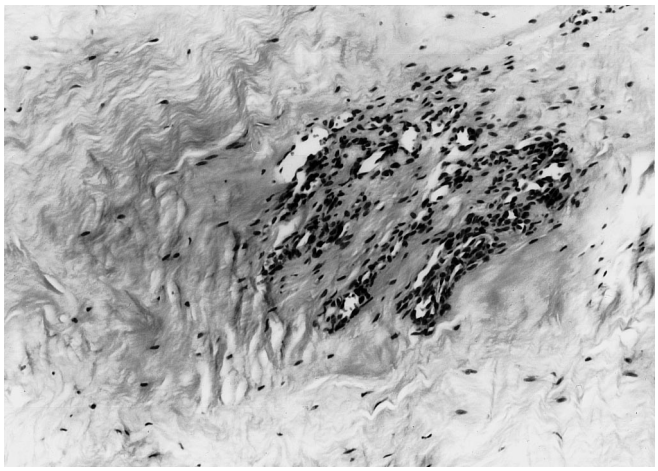

Fig. 6 Capillary vascularization in the inner annulus fibrosus of an intervertebral disk. (H&E, ×100)

In addition to normal SE T1-weighted images, SE T1-weighted frequency-selective fat-suppressed sequences were available for 19 of the 26 patients with enhancing disks. There was no difference in detection of enhancing areas. Fat-suppressed images revealed no additional enhancing lesions, but demonstrated the findings with higher lesion-to-bone-marrow contrast (Fig. 2, 5). The contrast between enhancing annulus fibrosus tissue and epidural fat was also increased. Bone marrow edema obscured on conventional T1-weighted post-Gd-DTPA images was demonstrated on enhanced fat-suppressed images in 13 segments (Figs. 2, 5).

At operation on seven patients with enhancing disks, the disks were found to be disintegrated. Parts of these seven disks were available for microbial cultures and histopathologic examination with H&E staining. Six of the seven disks showed focal capillary vascularization of the annulus fibrosus (Fig. 6). Additionally, in two patients fully developed granulation tissue was detected in the annulus fibrosus and in neighboring fibrous tissue as well. It also contained dissected peripheral nerves, detected by immunohistochemical reaction with antibodies to S-100 protein. Cultures of the specimens revealed no organisms.

On spinal radiographs, reduction of the disk space was found in all cases with band-like vascularizations. Osteophytic lipping was absent or minimal in 28 of 37 segments and moderate in 9. Sclerosis of the adjacent vertebrae (hemispherical spondylosclerosis) was found in nine patients, and marked sclerosis was present in two.

Nine patients with disk enhancement on MRI showed gas inclusions in the disk space on CT. These intradiskal gas accumulations had the same appearance as gas inclusions frequently found in degenerated disks.

All 26 patients showing enhancement within disks had suffered from severe local pain over the region of the affected disk. In all patients the pain had persisted for

weeks at least, and in six patients for years, with acute exacerbations. The pain was triggered or aggravated by exercise and movement and disappeared at rest. Seven patients had additional radicular symptoms. In one of these patients, disk herniation was found, in two previously operated patients epidural scarring was present, while in four cases no alterations of the nerve roots could be found on MRI. Only 5 of 37 vascularized disks showed posterior disk bulging impinging upon the dural sac. Eight patients had more than one affected disk. The 26 patients with enhancing disks did not show a significant difference in their pain scores to the 27 without disk enhancement.

There was no band-like vascularity in any of the disks of the 34 patients of the control group. In five patients, punctate Gd-DTPA uptake was noted in the dorsal part of the annulus fibrosus, at the L4/5 level in two patients, and at the L5/S1, L3/4, and T11/12 levels respectively in the remaining three patients. The difference between the control group and the back pain group in regard to band-like disk enhancement was highly significant ($p<0.001$, *t*-test).

Discussion

The intervertebral disks of neonates and infants are well vascularized [8–10]. The vessels enter the disk from the ossification center of the vertebra and from the longitudinal ligaments. For this reason, the intervertebral disks of children up to the age of 1.5–2 years show definite early enhancement after intravenous Gd administration [11]. These vessels rapidly obliterate during childhood, and from the age of about 13 years pathological examination shows no vessels in disks [8–10].

From the age of about 15 years, the annulus fibrosus shows oval or irregular areas of mucoid degeneration. When these become larger, small circular tears in the annulus fibrosus may result. The normal fibrous structure disappears and the lamellae may hyalinize [9, 10]. Circular tears do not communicate with the nucleus pulposus. From the age of 20 years, the circular tears may progress to radial tears extending from the nucleus pulposus to the outer areas of the annulus fibrosus. In accordance with the location of mucoid degeneration, radial tears are located posteriorly or dorsolaterally in the lower lumbar segments and anteriorly in the thoracic segments. As soon as radial tears reach the outer part of the annulus fibrosus and the longitudinal ligaments, vascularized granulation tissue can invade the tear and the adjacent disk. Although healing by scar tissue formation is possible, disk degeneration frequently progresses to complete disintegration of the disk. In advanced cases, Hirsch, Schajkowicz, and Hassler found the disk tissue to be replaced by a highly vascularized granulation tissue [9, 10]. Later on, scarring is found and vascularity is reduced.

Our results indicate that vascularization within the disk space is responsible for early contrast enhancement on MRI. Disk degeneration and formation of vascularized granulation tissue was detected more than half a century ago [8]. As yet, however, little attention has been paid to this phenomenon in medical imaging. Ross et al. were the first to demonstrate that tears of the annulus fibrosus could be diagnosed using Gd-DTPA [12]. Seven of our 26 patients with disk enhancement subsequently underwent surgery with posterior spondylodesis by internal fixation and ventral diskectomy. On histopathologic examination of the diskectomy specimens, vascular granulation tissue was detected in six of seven cases. Only in three of these six patients did macroscopic examination during surgery succeed in intentifying the disk vascularization. In one patient with positive MRI, histologic confirmation of vascularity failed. As the disk is usually destroyed and cannot be removed as a whole, a negative histological study does not necessarily exclude the presence of vascularity.

Owing the reduced water content in the nucleus pulposus and the central areas of the annulus fibrosus, low signal intensity in T2-weighted sequences is found in disk degeneration [3, 5, 13, 14]. Enhancing disks revealed low signal intensity on T2-weighted pulse sequences in five and increased signal intensity in three patients. Therefore, increased signal intensity within the disk space on T2-weighted images cannot be considered an unambiguous sign of septic spondylitis, but may also represent highly vascularized degenerative disk lesions in the thoracic and lumbar spine.

Intervertebral disk degeneration is a normal feature of aging. Even in asymptomatic individuals the frequency of disk degeneration increases in an almost linear relationship with age, and most individuals over the age of 70 years show disk degeneration [2, 3, 15]. Hypervascularity and band-like contrast enhancement were found in our patients only when disk height was reduced. On spinal radiographs, bony spurs were minor or absent. Therefore, mechanical instability may play an important role in disk vascularity. Probably the radiological definition of instability needs to be adjusted, since segments without translatory movement of more than 2 mm were unstable at operation and the enhancing disks were all disintegrated to a certain degree at operation. When bony contact is present at corresponding endplates, even minor movements in these segments can irritate the endplates, resulting in localized pain.

Pain in patients with disk enhancement was independent of concomitant bone marrow edema. Histologic examination of the disks revealed the presence of dissected nerve fibers in the vascularized tissue in two patients. Nerve endings are normally present only in the outer part of the annulus fibrosus, which is still vascularized. Vascularity is mandatory for the presence of nerve endings. We were able to demonstrate the presence of dissected

nerve fibers in central parts of vascularized disks in two specimens by positive immunohistochemical reaction with antibodies to S-100 protein.

Vascularization of disk tissue in patients with degenerative disk disease, like disk herniation, represents a complication in the degenerative process. It may be found in symptomatic patients with back pain who have had previous disk surgery. It is well known that postoperative granulation (scar) tissue demonstrates contrast enhancement. This enhancement is confined to the areas where the surgeon's instruments were, the epidural space, and, in the case of removal of the disk, in the disk space [16–18]. Marked enhancement is only seen up to 6 months postoperatively. Five of our previously operated patients underwent surgery 2–15 years ago. One patient, diagnosed 3 months postoperatively, demonstrated vascularity in the anterior part of the annulus; this part of the annulus was not operated on (Fig. 3). Just as patients are likely to develop bone marrow edema after chemonucleolysis, probably due to the sudden increase in segmental instability with insufficient bony compensation, mechanical instability after herniation or removal of the nucleus may also play the key role in the development of disk vascularity in patients who have had surgery.

Probably, diagnosis of a vascularized disk was frequently missed in the past due to the methods of investigation. MRI technique was aimed at demonstrating disk herniation, disk bulging, spinal stenosis, facet hypertrophy, or bone marrow changes; paramagnetic contrast agents were rarely used. For the assessment of epidural scarring, contrast-enhanced sequences were mostly employed in the axial plane, and thus disk enhancement could be missed [16–18].

Frequency-selective fat-suppressed sequences are helpful, but not essential to detect vascularized disks. We did not miss any lesion in our 19 affected segments on conventional enhanced T1-weighted images by comparing the latter with the unenhanced images, but the contrast of enhancing disk material or enhancing bone marrow edema to neighboring normal bone marrow or epidural fat was better on fat-suppressed enhanced images.

Secondary band-like vascularization of degenerated intervertebral disks is accompanied by local pain and is a condition that can be diagnosed on MRI. Correlation with surgical specimens suggests that the presence of a band of contrast enhancement along the vertebral endplates indicates disintegration of the entire disk. Punctate uptake in the outer parts of the annulus was also found in the control group and indicates the presence of limited annular defects that are not necessarily symptomatic.

In disk degeneration, erosions of the adjacent vertebral endplates may be present, but the peripheral cortical bone of the vertebra is intact and often sclerosis can be found. Disk infections, on the other hand, are frequently associated with destruction of the cortical borders of the vertebra; the distinct dark rim of the endplate is then often focally not visible on T1-weighted images. A gas inclusion on CT helps to distinguish degenerative disk vascularization in erosive osteochondritis from spinal infection.

There is a high prevalence of degenerative lumbar disks in the MRI studies of people without back pain [19], and all degrees of disk degeneration can be found generally in asympatomatic populations [20]. However, band-like vascularity in the disk space at the disk-vertebral junction was associated with severe painful back syndromes in all of our patients. As bony changes and spurs at the endplates were absent or only moderately developed, segmental instability may play a causative role in the development of disk vascularity. Secondary disk vascularization is a clinical condition which can easily be diagnosed only by means of contrast-enhanced MRI. Therefore, MRI protocols in the work-up of patients with painful back syndromes should include the use of paramagnetic contrast medium and sagittal imaging after contrast injection, if CT studies have not shown disk herniation or other significant findings that could explain the patients' symptoms.

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