AJNR

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AJNR Am J Neuroradiol 1988, 9 (6) 1215-1220
http://www.ajnr.org/content/9/6/1215

MR Imaging of the Pars Interarticularis

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MR imaging of the lumbar spine has become a useful method for the noninvasive evaluation of low back pain. However, bone abnormalities are more difficult to detect than soft-tissue lesions, such as herniated disk. We reviewed 14 MR images of the lumbar spine in adults with spondylolisthesis. These were correlated with CT scans and plain films in all cases. From the CT scans and plain films we found that seven patients had spondylolysis and that seven had other causes for their spondylolisthesis. It was our opinion that the MR images suggested an abnormality of the pars interarticularis in all seven of the cases confirmed to have spondylolysis and in six of the seven patients that did not have spondylolysis. We also studied four cadaver lumbar spines, obtained as blocks of tissue, and scanned in the coronal, sagittal, and axial planes with MR and in the sagittal and axial planes with CT. The tissue blocks were then sectioned in the sagittal plane. Spondylolysis is suggested on sagittal MR images when there is an inability to resolve the marrow signal in the pars as uninterrupted from the superior to the inferior facet. This is caused by a dark signal on all pulsing sequences in the pars resulting from marginal sclerosis at the site of the break. If there is also a gap at the site of the break then there will also be an increased signal in the gap resulting from the presence of soft tissue.

We found four situations in which the pars can simulate spondylolysis on sagittal MR images: (1) sclerosis of the neck of the pars; (2) partial volume imaging of the degenerative spur of the superior facet slightly lateral to the pars; (3) partial facetectomy; and (4) osteoblastic metastatic replacement of the marrow of the pars.

MR imaging is well-suited to the evaluation of disk disease [1–5]. As a single technique, however, it may not be well-suited to the evaluation of all causes of low back pain, because bone abnormalities are more difficult to detect. The detailed study of bone architecture and abnormalities has remained in the realm of high-resolution CT. In our institution most lumbar spine MR studies are requested for patients with low back pain to rule out herniated disk. Rarely do CT and plain films accompany the patient; for some, MR is the initial study. Therefore, interpretations are frequently made without correlative studies. Despite the fact that bone abnormalities cannot be evaluated as well by MR as by CT or plain films, we believe there is information that can be gleaned from the routine MR that can lead to the correct impression or at least raise the level of suspicion sufficiently to suggest the need for CT or plain-film corroboration. This report describes the MR, CT, and plain-film findings of the pars interarticularis in 14 patients with spondylolisthesis together with MR, CT, and anatomic studies of the pars in four randomly selected cadaver specimens.

Materials and Methods

Cadaver Study

We studied four randomly selected fixed cadaver lumbar spines. Each spine was obtained as a block of tissue and scanned with MR and CT. The tissue specimens were then sectioned

This article appears in the November/December 1988 issue of *AJNR* and the February 1989 issue of *AJR*.

Received October 21, 1987; accepted after revision April 5, 1988.

Presented at the annual meeting of the American Society of Neuroradiology, New York, May 1987.

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***AJNR* 9:1215–1220, November/December 1988**
0195–6108/88/0906–1215

in the sagittal plane for anatomic evaluation and correlation with the imaging studies. All were scanned on the GE 1.5-T magnet in the sagittal, axial, and coronal planes using both a single-echo sequence, 600–800/25/2 (TR/TE/excitations), 256 × 256 matrix, and 16-cm field of view, and a multi-spin-echo sequence, 2500–3000/20–25/2–4, 128 × 256 or 256 × 256 matrix, and 16-cm field of view. The factors for the multiecho sequence were varied slightly in an effort to optimize scanning time and signal-to-noise ratio. All were scanned with a 5-mm slice thickness and 1-mm gap. Either the head or knee coil was used depending on the size of the block of tissue. One specimen was scanned on a GE 8800 CT scanner using contiguous 1.5-mm slices, and the other three specimens were scanned on the GE 9800 scanner using contiguous 3-mm slices. Bone algorithms were used for all images.

Clinical Study

We received 14 MR images of the lumbar spine in adults with spondylolisthesis. Patients included nine men and five women whose ages ranged from 18 to 63 years old. The MR images were correlated with CT scans and plain films in all cases. All patients were imaged on a GE 1.5-T system with a 5.5 × 11-in. planar coil. Our standard lumbar spine protocol includes imaging in the sagittal and axial planes with a multi-spin-echo sequence (3000/20–25/2), 128 × 256 matrix, 5-mm slice thickness, and 1-mm gap. The field of view was 20–24 cm in the sagittal plane and 16–20 cm in the axial plane, depending on the girth of the patient. No special imaging technique was employed to improve visualization of the posterior elements. We applied the hypothesis that if pars defects on CT scans and plain films are appreciated by a break in the bone continuity, then on sagittal MR images a pars defect will be appreciated by a break in the continuity of the marrow signal. In other words, there must be an uninterrupted marrow signal from the superior to the inferior facet to indicate a normal pars interarticularis.

Results

A summary of the cadaveric and clinical findings is illustrated schematically in Figure 1.

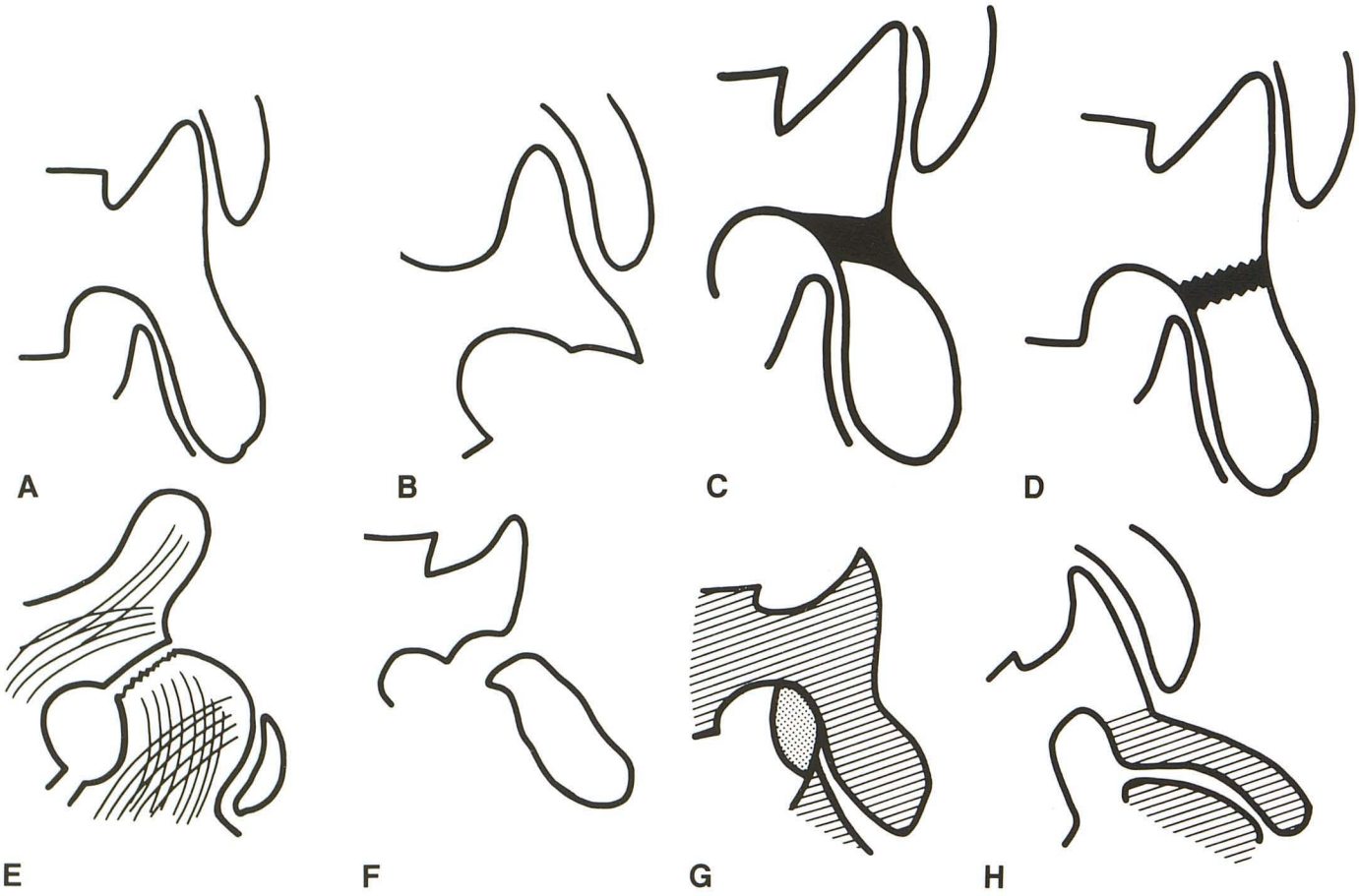

Fig. 1.—Schematic drawings summarize sagittal MR findings of clinical and cadaver studies.
***A*, Normal pars, no sclerosis, marrow signal intact from superior to inferior facet.**
***B*, Partial facetectomy.**
***C*, Normal but sclerotic pars, marrow signal interrupted.**
***D*, Spondylolysis with sclerotic margins, no gap.**
***E*, Partial volume imaging of S1 superior facet and L5 pedicle simulating a break in the pars.**
***F*, Spondylolysis with gap.**
***G*, Metastatic disease with diffusely abnormal marrow signal (*diagonal lines*) and adjacent soft tissue mass (*dotted area*).**
***H*, Thin, sclerotic pars, degenerated facet with abnormal marrow signal (*diagonal lines*).**

Cadaver Study

All the cadaver specimens had varying degrees of degenerative disk and facet changes at L4–L5 and L5–S1. None had spondylolysis, spondylolisthesis, blastic or lytic metastatic disease, or evidence of prior surgery or trauma. Of the 16 pars surveyed in four cadavers at L4 and L5, two had interruption of the marrow signal by MR. Direct sagittal CT revealed bone sclerosis. Figure 2 illustrates the CT and MR findings and the corresponding anatomic sections.

Clinical Study

From the CT scans and plain films we found that seven patients had bilateral spondylolysis and that seven had other causes for their spondylolisthesis. Four had degenerative spondylolisthesis; one had laminectomy, partial facetectomy, and posterior fusion; and one had metastatic breast carcinoma. One patient had an elongated, thin, sclerotic pars with degenerative changes in the posterior facets. MR suggested an abnormality of the pars interarticularis in all of the seven cases with confirmed spondylolysis and in six of the seven cases that did not have spondylolysis. Figures 3 and 4 illustrate the findings of spondylolysis (compare with Figs. 1D and 1F). By applying the criteria of an intact marrow signal from the superior to the inferior facet, we found four situations in which the pars can simulate spondylolysis on sagittal MR images: (1) sclerosis of the neck of the pars, Figure 4 (compare with Fig. 1C); (2) partial volume imaging of the spur arising from the superior facet slightly lateral to the pars, Figure 5 (compare with Fig. 1E); (3) partial facetectomy, Figure 6 (compare with Fig. 1B); and (4) blastic metastatic replacement of the marrow of the pars, Figure 7 (compare with Fig. 1G).

Discussion

Slippage of the spine or "luxation of the lumbosacral joint" was described earlier [6] but Kilian [7] introduced the term spondylolisthesis to describe a forward slip of L5 on S1. The Greek word *olisthesis* means to slip or slide. Because the lordotic curve causes a downward tilt of the anterior aspect of the upper sacral endplate and usually of the lower lumbar endplate, the term spondylolisthesis has become synonymous with *forward* displacement of the upper vertebral body down the slope of the superior endplate of the lower vertebral body. The term retrolisthesis refers to posterior displacement of the upper vertebral body upon the lower. Though lateral plain films, sagittal CT scans, or MR images suggest a symmetric forward slip, most of the time the slip is asymmetric, causing a rotatory component [8].

Newman [9] classified spondylolisthesis into five types, as follows: type I, dysplastic—the result of an associated congenital abnormality of the arch of S1 and L5; type II, isthmic—

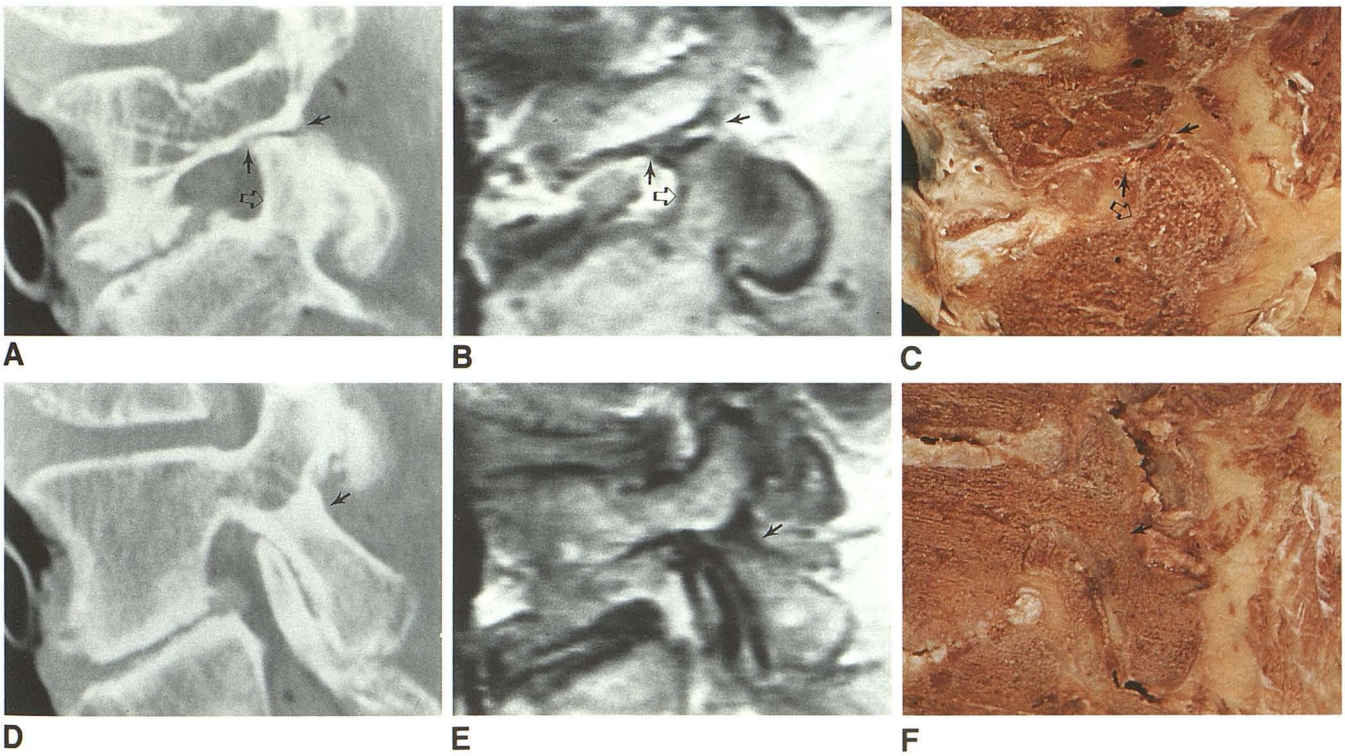

Fig. 2.—CT, MR, and sagittal cadaver sections. Cadaver study demonstrates false appearance of lysis when scan plane is slightly lateral to pars. Images were acquired in the knee coil (2500/25/4), 128 × 256 matrix.

***A–C*, Note superior facet of S1 (*open arrow*) and false break between *arrows*. Compare with Fig. 5A.**

***D–F*, 6-mm slice medial to *A–C* demonstrates a sclerotic but intact pars interarticularis (*arrow*).**

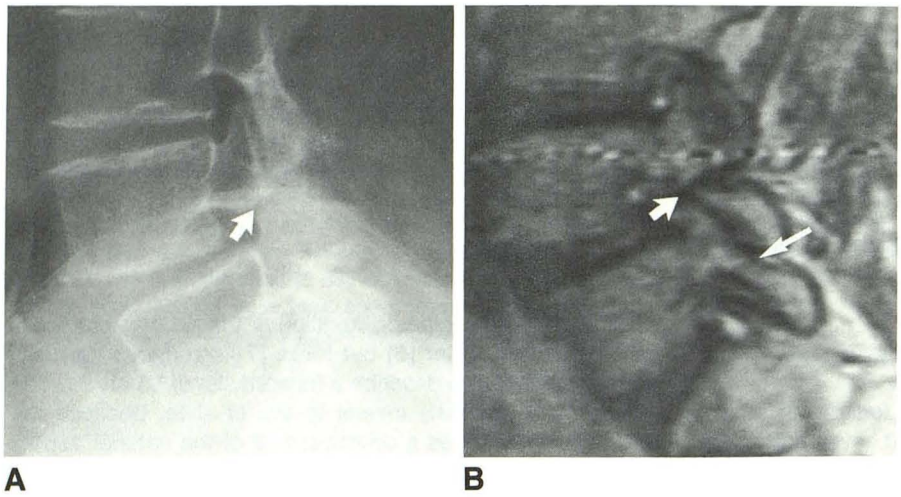

Fig. 3.—63-year-old woman with low back pain and history of L2–L5 laminectomy.

A, Lateral lumbar film demonstrates a grade I spondylolisthesis of L4 with a pars fracture (*arrow*).

B, Sagittal MR image (3000/25/2) shows a thin black line crossing the pars of L4, interrupting continuity of marrow (*short arrow*). Note that intact pars at L5 has an uninterrupted marrow signal from superior to inferior facet (*long arrow*). Defects were bilateral but only one side is depicted here.

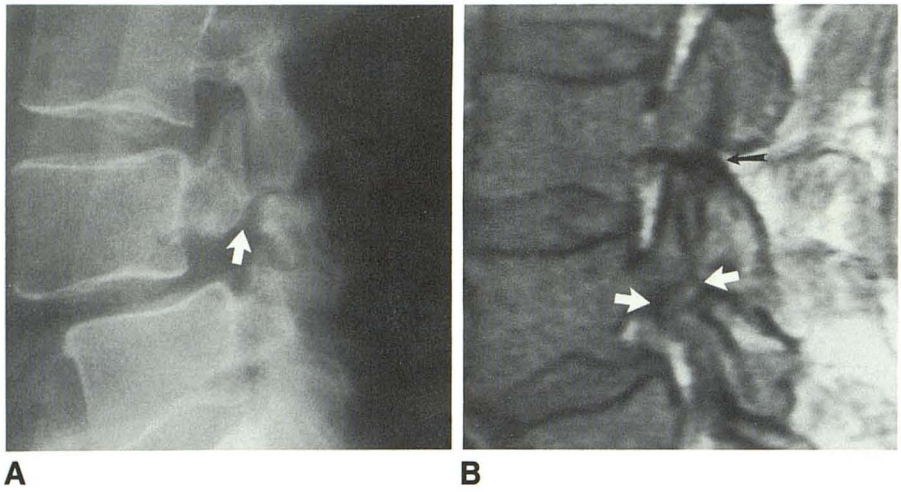

Fig. 4.—45-year-old man with history of spondylolisthesis of L4 on L5 presented with radicular type right leg pain.

A, Lateral plain film demonstrates a fracture of the pars interarticularis of L4 with a grade I spondylolisthesis of L4 on L5. Notice gap in pars defect (*arrow*).

B, Sagittal MR image (3000/25/2) shows fracture of pars (*white arrows*), gap in defect, and stenosis of L4–L5 neural foramen. Defects were bilateral but only one side is depicted here. At L3 there is an intact but sclerotic pars (*black arrow*).

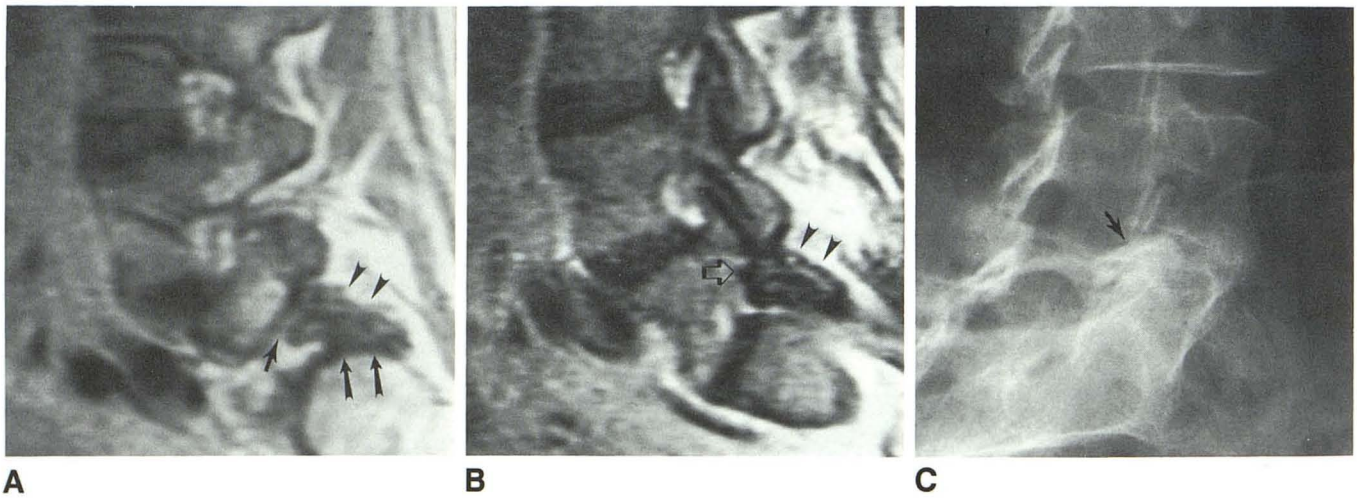

Fig. 5.—54-year-old woman with back pain and history of mastectomy.

A and *B*, Adjacent sagittal MR images (3000/25/2) separated by 6 mm show abnormal marrow signal in pars (*open arrow*) in *B* and irregularity of inferior facet (*arrowheads*). Note a gap suggesting a break just beneath pedicle in *A* (*short arrow*). Figure A is more lateral than B and there is partial volume imaging of the superior facet (pair of *long arrows*). Compare with Figs. 1E and 2A–C.

C, Oblique plain film of left side shows elongated, sclerotic pars interarticularis and spurring of L5–S1 facet but no lysis (*arrow*).

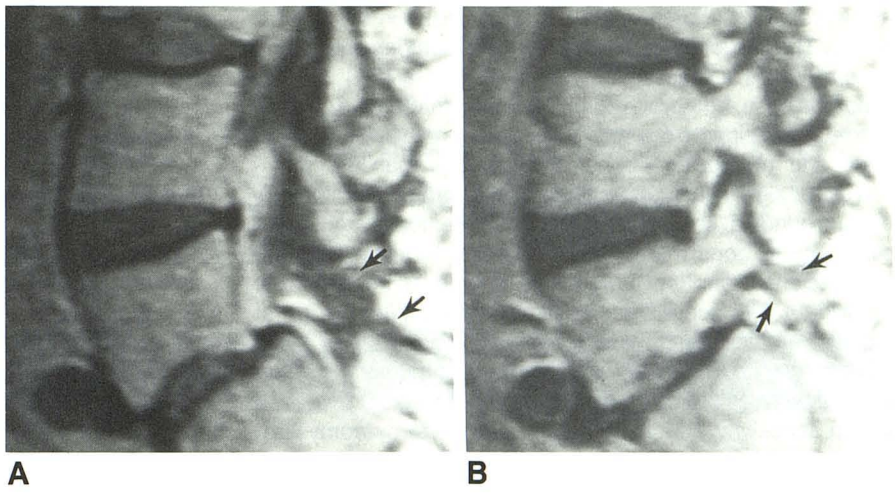

Fig. 6.—62-year-old man with history of laminectomy and fusion presented with acute exacerbation of bilateral lower-extremity weakness.

***A* and *B*, Adjacent sagittal MR images (3000/25/2) separated by 6 mm fail to identify entire pars/inferior facet structure (*arrows*) at L5. Left side is depicted. Plain films revealed fusion of L4–S1 and partial inferior facetectomies bilaterally at L5.**

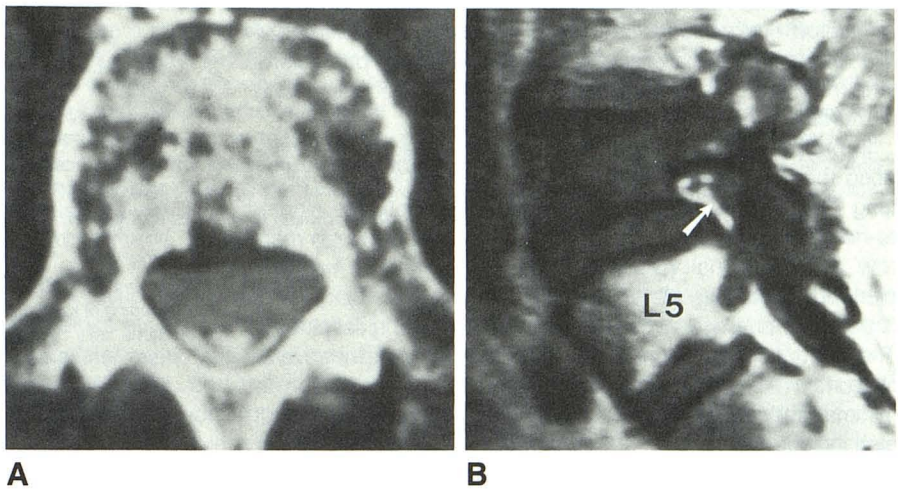

Fig. 7.—63-year-old man with history of metastatic breast cancer with new onset of radicular type right leg pain.

***A*, Axial CT scan of L4 shows blastic changes in the body and posterior elements but no spondylolysis.**

***B*, Sagittal MR image (3000/25/2) shows abnormally low marrow signal in the body, pars, and inferior facet of L4 and the superior facet and pars of L5 with soft tissue narrowing the L4–L5 neural foramen (*arrow*), all compatible with metastasis.**

the result of a defect in the pars interarticularis that may be (a) a fatigue fracture, (b) an elongated but intact pars, or (c) an acute fracture; type III, degenerative—the result of a long-standing intersegmental instability and degeneration of the disk and facets; type IV, traumatic—the result of fractures in areas of the posterior elements other than the pars interarticularis; and type V, pathologic—the result of generalized or localized bone disease.

Symptoms

Symptoms of spondylolisthesis run the whole gamut from no symptoms to mild or severe, and intermittent to constant backache with or without radicular complaints. There may also be no complaint of backache despite symptoms and signs of nerve root compression or cauda equina syndrome. Stenosis of the neural foramena at the level of the slip and in some cases secondary degenerative spurs further narrowing the foramena are important factors in nerve root compression in this syndrome [10].

Imaging

CT has added much to the plain-film and myelographic evaluation of spondylolisthesis, particularly because of the superior resolution of small bone abnormalities of the neural arch and the added soft-tissue detail that facilitates the evaluation of spinal canal and neural foraminal stenosis. The "incomplete ring" sign describes the axial CT findings of spondylolysis [11]. However, the presence of a grade I spondylolisthesis may be missed if only the axial images are evaluated. Often, sagittal and coronal reformatting of high-resolution axial images add a new perspective to foraminal stenosis and the interrelationships of anomalies, slips, fractures, or bone spurs in three-dimensional space [12, 13]. The use of a midline sagittally reformatted image can demonstrate the presence of the pseudobulging disk at the level of the slip [14].

MR has proved to be a significant addition to the imaging of the lumbar spine. It has for the first time revealed noninvasively the internal architecture of the disk itself [1–3] and

its degree of hydration relative to other disks in the sagittal image. The detection of disk herniation is comparable to, and in some cases surpasses, CT and myelography [2, 4, 5]. This is not the case, however, regarding bone structures. Because of the lack of signal from solid structures—namely the cortical bone and trabeculae—bone abnormalities manifest themselves by signal changes in the marrow and by their effects on surrounding soft tissues. MR has demonstrated great sensitivity to bone marrow abnormalities. Moore et al. [15] reported an increase in T1 relaxation times in the bone marrow of children with acute lymphocytic leukemia. With aging, fat replaces hematopoetic marrow causing a decrease in T1 and T2 relaxation times [16]. Aseptic necrosis of the bone marrow is manifested as a prolonged T1 relaxation time [17]. MR has a high sensitivity and specificity for vertebral osteomyelitis, demonstrating prolonged T1 and T2 relaxation times in the vertebral body [18]. Neoplasms demonstrate prolonged T1 and T2 relaxation times in the vertebral body, often appearing multiple, of varying size and location [19]. If these tumors cause an osteoblastic response, there is a shortened T2 relaxation time. Gross features of fractures/dislocations of the vertebral body can also be easily appreciated, particularly with respect to encroachment upon the spinal canal and compression of the cord [20].

In our study, we found that the optimal images for evaluating the pars interarticularis were the short TR/short TE or long TR/short TE sequence. These factors optimize signal-to-noise ratio and allow the greatest contrast between marrow and the signal void of cortical bone. There is no best plane for evaluating the entire pars interarticularis because it is obliquely oriented to the sagittal, coronal, and axial planes. The sagittal plane is more useful than the other two for several reasons. The obliquity of the pars in the sagittal plane is minimal and a 5-mm slice thickness properly positioned will also include the pedicle, superior, and inferior facets. Abnormal marrow signal in the pars can be easily compared with adjacent marrow containing structures in the same image. In those individuals without scoliosis the pars interarticularis of all the lumbar segments can be evaluated on one or occasionally two adjacent sagittal images. Furthermore, spondylolisthesis and foraminal stenosis are best appreciated in the sagittal plane. These are secondary findings, of course, and may not coexist with a pars abnormality; but these findings are more obvious, indicating a closer study of the images to ascertain the cause.

Our high false-positive rate was most likely due to the rather inclusive wording of the hypothesis. An interruption in the continuity of the marrow signal cannot be synonymous with a break in the pars because any process that replaces marrow (i.e., lytic or blastic metastasis or bony sclerosis) should alter the marrow signal. The false positives encountered in our series had other features that were unique to themselves. The patient with metastasis (Fig. 7) had lesions in other marrow-containing structures and soft-tissue metastasis in the neural foramen. The patient with partial inferior facetectomy (Fig. 6) on two adjacent images had no clearly defined inferior facet. The false break in the pars encountered in those with degenerative facet disease was due to partial volume averaging of the superior facet spur and the adjacent pedicle (Figs. 2 and 5). However, one should be able to identify correctly the superior facet arising from the lower vertebral segment, and on the more medial adjacent image the intact pars should be seen. Sclerosis of the pars is the false-positive appearance that most resembles spondylolysis when there is minimal spondylolisthesis. Higher grades of spondylolisthesis due to spondylolysis (≥ grade II) should leave a gap in the pars defect (Fig. 4). Our true positives all demonstrated marrow abnormalities limited only to the pars itself, corresponding closely with the extent of abnormality seen on plain films and/or CT.

In conclusion, much information can be gleaned from the routine sagittal MR. Pars abnormalities can be detected without the use of additional sequences. The exact nature of the pars abnormality may remain obscure, but by using our criteria, one can acquire information from the routine sagittal MR that may raise the level of suspicion sufficiently to recommend CT and/or plain-film corroboration.

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