Seminars in ULTRASOUND CT and MRI

# Advances in MR Imaging of Vertebral Collapse

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**Vertebral collapse is a frequently encountered entity in clinical practice. While diagnosing acute, benign traumatic types is usually not complicated, difficulties arise in determining the etiology of vertebral collapse when there is no history of significant trauma, especially in older populations. Considering up to one-third of vertebral collapse in patients with a known primary malignancy are benign,[1] the diagnosis becomes even more difficult when there is a history of malignancy. Additionally, because primary cancer patients may be immunocompromised, the possibility of infectious vertebral collapse should also be entertained. The purpose of this article is to review all recent magnetic resonance imaging aspects of differentiating osteoporotic, malignant, and infectious vertebral collapse.**
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Vertebral collapse is a frequently encountered entity in clinical practice, especially in older adults. While diagnosing acute, benign traumatic types is usually not complicated, difficulties arise in determining the etiology of vertebral collapse when there is no history of significant trauma, especially in older populations. Considering up to one-third of vertebral collapse in patients with a known primary malignancy are benign,[1] the diagnosis becomes even more difficult when there is a history of malignancy. Additionally, because primary cancer patients may be immunocompromised, the possibility of infectious vertebral collapse should also be entertained.

Vertebral collapse is often secondary to osteoporosis, which is more common in women. In the United States, 25% of postmenopausal women have a vertebral compression fracture and this prevalence steadily increases with age.[2] Those diagnosed with vertebral collapse have a 15% higher mortality rate than those without this condition.[2] Because of the varied and diverse therapeutic options, the ability to distinguish osteoporotic, malignant, and infectious collapse is of considerable clinical interest. The purpose of this article is to review all recent magnetic resonance (MR) imaging aspects of differentiating osteoporotic, malignant, and infectious vertebral collapse.

## Osteoporotic Collapse

Osteoporotic vertebral collapse in the acute setting may be difficult to differentiate from pathologic causes. Additionally, multiple lesions may occur with varying features.[3-6] In osteoporotic collapse, edema and fluid replace the fatty marrow within the vertebral body, appearing hypointense on T1-weighted images and isointense to hyperintense on T2-weighted images.[3,4,6,7] The acute signal abnormalities may be complete, incomplete (heterogeneous), or band-like.[1,3,4,6,8-11] The area of signal abnormality is well-defined in 71% of cases and ill-defined in 29%.[12] Most benign collapses have some amount of normal fatty marrow in the vertebral body on T1-weighted images[1,3,4,6,11,13] (Figs 1, 2, 3, 4, and 5). The areas of normal, preserved fatty marrow are opposite of the fractured endplate and the band-like hypointensity seen adjacent to the preserved marrow on T1-weighted images is considered specific for osteoporotic collapse[4,5,14] (Table 1). A minority may have complete vertebral body involvement without any remaining fatty marrow.[9,10,11,13,14] It is these cases that may be easily confused with malignant collapse.

On T2-weighted images, benign collapse has a variety of appearances, ranging from normal to heterogeneous to homogeneously abnormal signal.[3] This spectrum of findings may be related to the age of the collapse in this study.[3] In chronic benign fractures, normal conversion back to fatty marrow is expected.[1,15] Within 3 months of injury, there is almost always some restoration of fatty marrow, and a linear hypointense horizontal signal may persist.[5,6,7,11,15] Persistent hypointensity on T1-weighted images, representing compact bone and/or marrow replacement by fibrosis may sometimes be mistaken for malignancy.[1] Return of signal intensity from hyperintense to isointense on T2-weighted images is strong evidence of a nonmalignant collapse.[1,6]

In approximately 19% of benign collapse cases there are focal areas of signal abnormality on T1-weighted images in other adjacent vertebrae.[4] While most of these are likely be-

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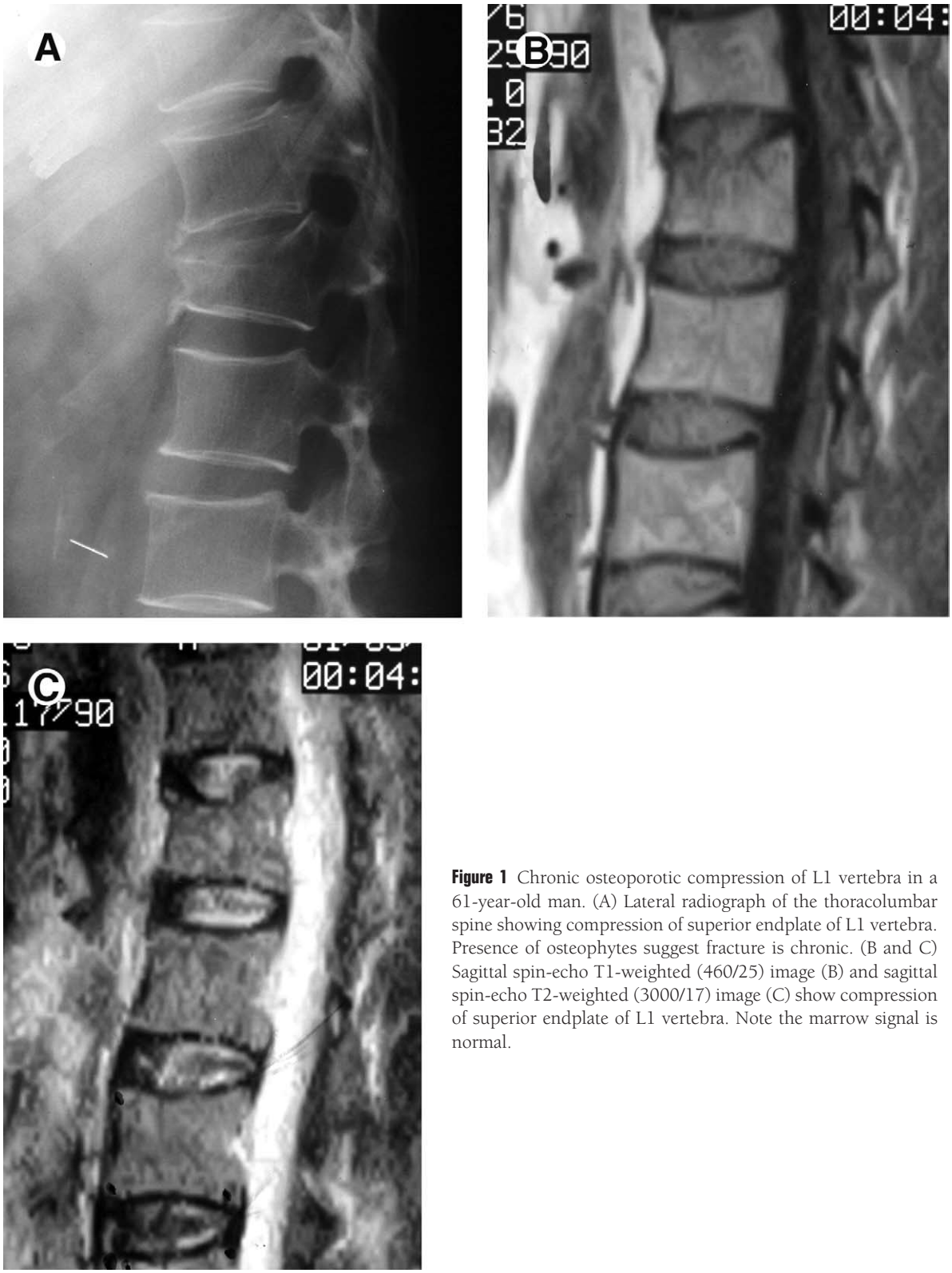


**Figure 1** Chronic osteoporotic compression of L1 vertebra in a 61-year-old man. (A) Lateral radiograph of the thoracolumbar spine showing compression of superior endplate of L1 vertebra. Presence of osteophytes suggest fracture is chronic. (B and C) Sagittal spin-echo T1-weighted (460/25) image (B) and sagittal spin-echo T2-weighted (3000/17) image (C) show compression of superior endplate of L1 vertebra. Note the marrow signal is normal.

nign (fracture lines, bone impaction, or Schmorl's nodes), differentiation in some cases from metastasis may not always be possible.[4]

Although osteoporotic collapse may show a bulging or convex posterior cortex in 2% to 19% of cases (typically a feature of malignant collapse),[4,10,14] the majority show preservation of normal concave posterior cortex and pedicles.[4,7] Retropulsion into the spinal canal, or more specifically, a posterior-angulated fragment of the posterosuperior or posteroinferior vertebral body is highly characteristic of benign collapse, but only occurs in a minority of cases[4,6,7] (Fig 3). Only one published case with a posterior-angulated fragment

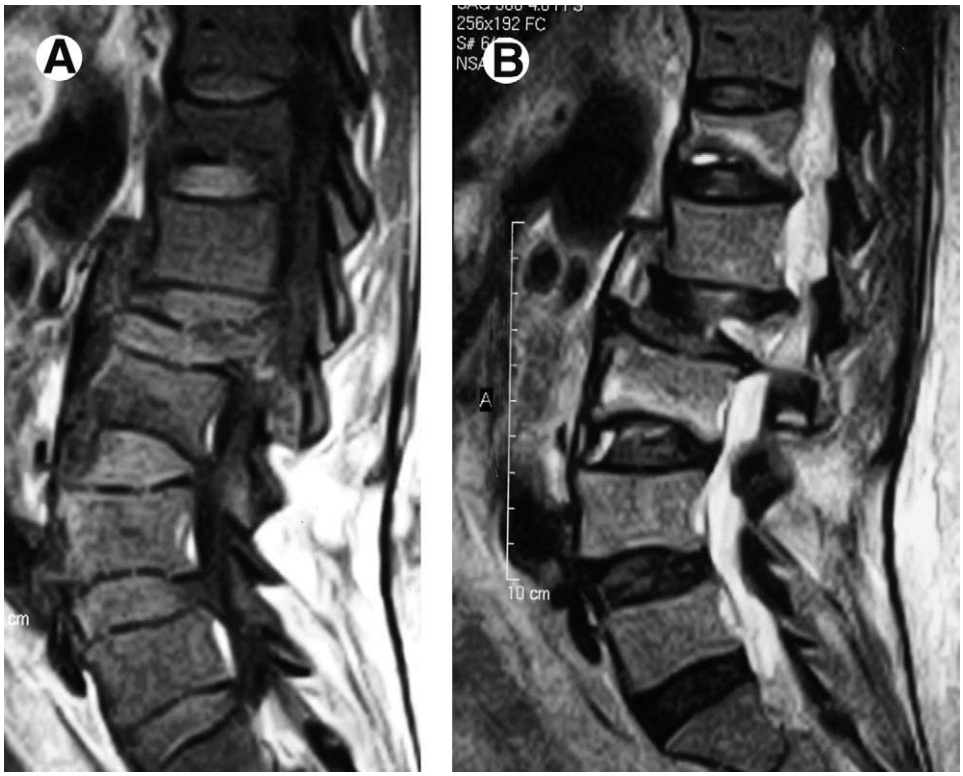


**Figure 2** Osteoporotic compression fracture of T12, L2, and L3 vertebrae in a 78-year-old woman. (A and B) Sagittal spin-echo T1-weighted (500/20) image with fat saturation (A), sagittal spin-echo T2-weighted (4200/120) image (B) show three vertebral compressions. Note the linear, bright fluid line at T12, L2, and L3.

in a malignant collapse is known.[16] In fact, a review of the cases prior to the published recognition of this sign demonstrate the posterior-angulated fragment in cases of atypical osteoporotic collapse that were misdiagnosed as malignant collapse.[9] Abnormal signal of one or both pedicles may occur in 6% to 29% of benign collapse.[4,10,12] Benign pediculate involvement portend marrow changes in only a portion of the pedicle,[14] and the size of the pedicle does not expand.[12]

The linear intravertebral vacuum sign of Kümmell's disease, although an uncommon finding and better depicted on computed tomography (CT) and radiographs, may help in diagnosing benign osteoporotic collapse due to osteonecrosis on MR imaging[17] (Fig 6). Dupuy and colleagues[18] describe a vertebral fluid collection as a potential sign of avascular necrosis. The fluid sign is seen in 12% to 50% of osteoporotic collapses[4,8,9] (Figs 2 and 4); however, this sign may also be found in 5% to 6% of pathologic collapses.[4,8] The most common morphology of the fluid sign was linear, followed by triangular, then focal, and was usually located adjacent to the anterior portion of the superior endplate.[8] There is a significant association between severity of the fracture and occurrence of the fluid sign.[8] Baur and colleagues[8] suggest that in these acute osteoporotic collapses with bone marrow edema, fluid is pressed into the space of osteonecrosis and causes the fluid sign. Thus, the fluid sign probably represents the MR imaging appearance of the known intravertebral vacuum sign as seen on radiographs and CT. Some authors suggest the possibility of the presence of acute vertebral ischemia as the cause of the fluid sign, based on its linear configuration, location adjacent to the endplate, and vertebral vascular supply.[19]

Fragmentation presenting in about 10% (5 of 52 cases) of benign osteoporotic collapse was described as a secondary finding that did not occur in any case of malignant collapse (n = 25) in a study by Yuh and colleagues.[3] The authors suggest that fragmentation was possibly due to the higher force required to fracture normal vertebrae and osteoporotic vertebrae than in vertebrae affected by malignancy. In this study, fragmentation was found more commonly in traumatic cases than in osteoporotic cases.[3] Shih and colleagues,[12] in a study of only solitary cases of collapse, noted cortical disruption in 52% (11 of 21 cases) of benign collapse.

Evidence of a paraspinal mass may be seen in a minority of patients with osteoporotic collapse. In the study by An and colleagues,[5] 2 of 11 patients had a paraspinal mass. This is in contrast to the study of Shih and colleagues,[12] in which a surprising 100% of solitary benign collapse had a thin rim-shaped paraspinal soft tissue lesion. The authors attempt to justify this finding by explaining the presence of paraspinal soft tissue injury in theoretical cases of burst fracture, but do not note how many in their series were actually a burst-type of collapse. Paraspinal soft tissue edema is more readily seen in traumatic collapse and malignant collapse.[3] However, epidural extension is rare, having at most been reported in 1 patient of a series of 11,[5] and in other studies there have been none.[4,10,13] Hematoma formation with benign collapse may mimic soft tissue masses and is a nonspecific finding.[1] Disk involvement is rarely seen but is more common in traumatic and osteoporotic collapse than with malignant collapse.[3]

On intravenous contrast-enhanced images, 84% of osteoporotic collapsed vertebrae exhibit a "return to normal" signal intensity (isointense to adjacent normal vertebrae) on non-fat-suppressed T1-weighted images.[4] At least 70% of these will also have areas of linear hypointensity or

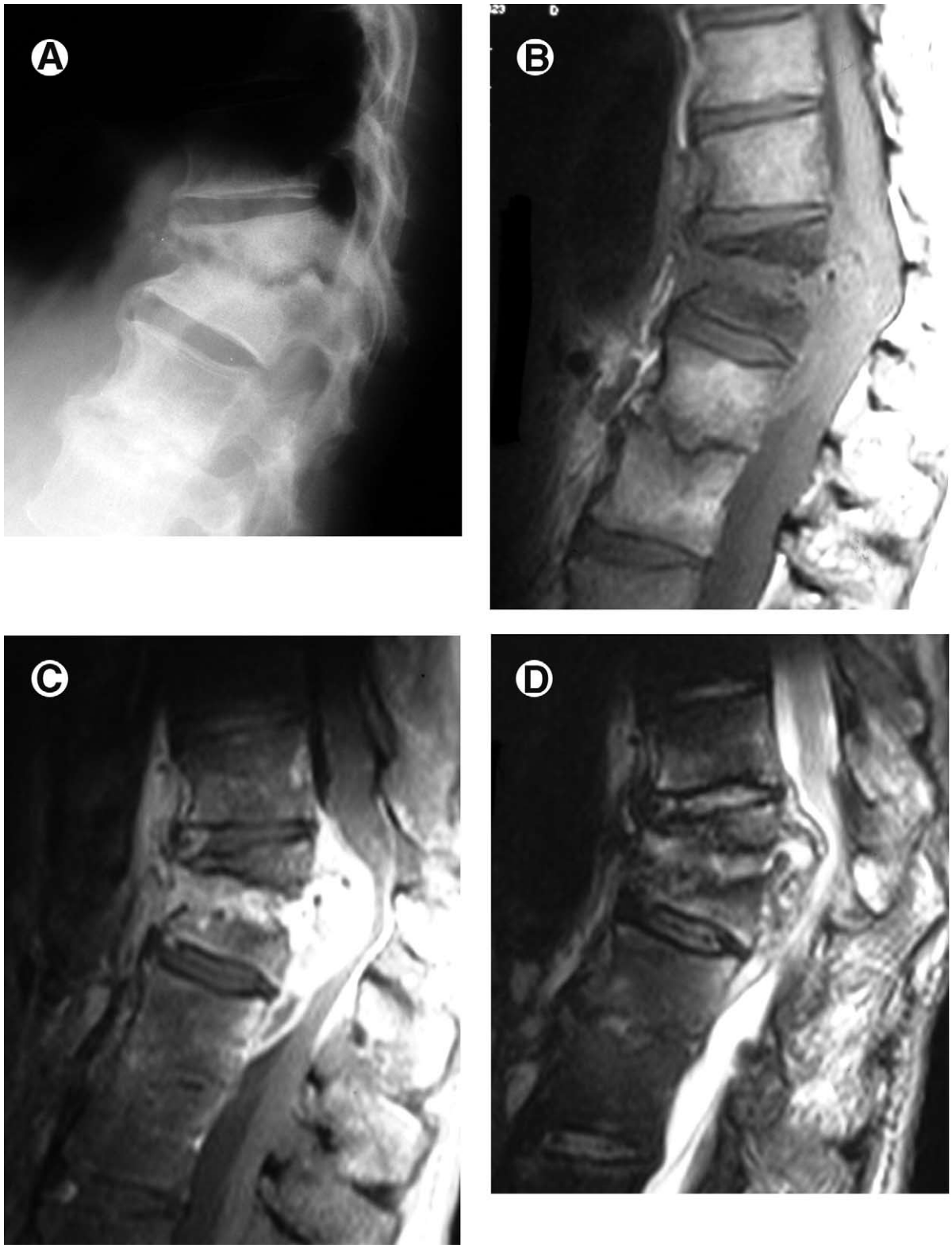


**Figure 3** Traumatic collapse of thoracolumbar junction mimicking infectious spondylitis in a 59-year-old man. (A–D) Plain radiograph (A), sagittal spin-echo T1-weighted (498/10) image (B), sagittal spin-echo T1-weighted (637/9) image with fat saturation and gadolinium contrast (C), and sagittal spin-echo T2-weighted (3000/96) image with fat saturation (D) show collapse of two vertebral bodies with large posterior osteophyte and kyphotic angulation deformity of the spine. Extensive erosion of the endplates and presence of fluid in the collapsed region suggests benignity of the process. Note abnormal signal in the marrow, which has some fatty marrow preserved.

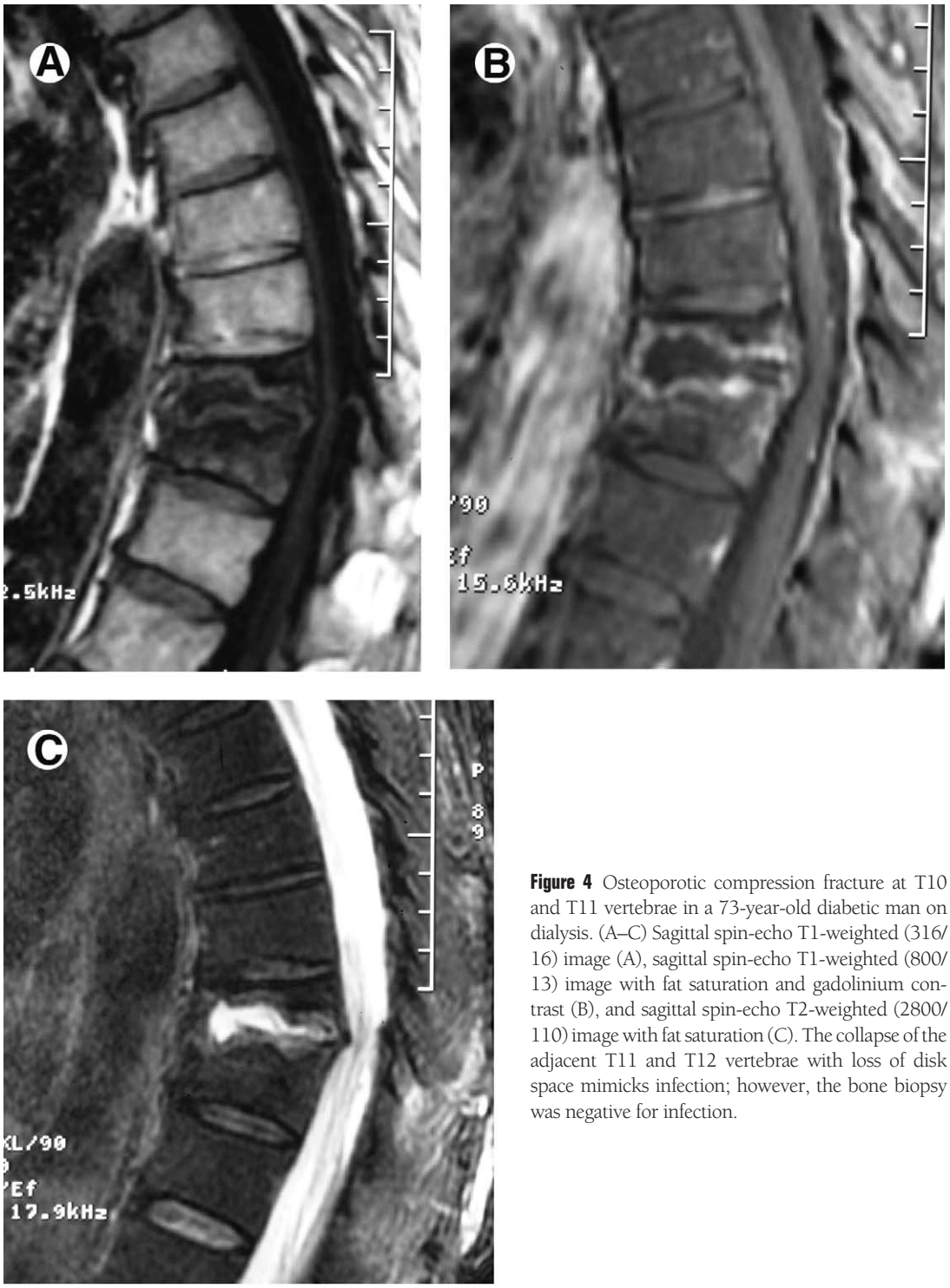


**Figure 4** Osteoporotic compression fracture at T10 and T11 vertebrae in a 73-year-old diabetic man on dialysis. (A–C) Sagittal spin-echo T1-weighted (316/16) image (A), sagittal spin-echo T1-weighted (800/13) image with fat saturation and gadolinium contrast (B), and sagittal spin-echo T2-weighted (2800/110) image with fat saturation (C). The collapse of the adjacent T11 and T12 vertebrae with loss of disk space mimicks infection; however, the bone biopsy was negative for infection.

hyperintensity, probably related to the fracture line.[4] Intense enhancement of benign, osteoporotic collapse is a feature of acute cases,[4,5] while mild enhancement is a feature of subacute or chronic benign collapse.[12] In a study of 21 cases of solitary benign vertebral collapse that were not controlled for age, two-thirds showed mild enhancement, and in the remaining third there was marked intense enhancement.[12] Enhancement may be diffuse homogeneous or patchy heterogeneous.[7] Homogeneous enhancement was seen in 62% and heterogeneous enhancement in 38% of osteoporotic collapse.[12] In the cases of heterogeneous enhancement, the posterior vertebral body usually showed greater enhancement than the anterior portion.[12] The authors attribute this to uneven contrast medium retention due to blood stasis as a result of the fracture.[12] Enhancement may also be due to contrast leakage through compromised vessels, and the presence of granulation tissue.[20] In the remaining cases that do not "return to nor-


**Figure 5** Insufficiency sacral fracture in a 43-year-old woman with history of invasive squamous cell carcinoma of the cervix, status post-radiotherapy. (A–C) Selected image from whole-body $^{99m}$Tc-methylene diphosphonate bone scan (posterior view) (A), axial spin-echo T2-weighted (5000/126) image (B), and coronal CT sacrum (C) show focal uptake in left sacrum. The MRI reveals high signal in the left sacrum. The CT examination shows typical vertebral subchondral insufficiency fracture on the left side.

mal," there is peripheral enhancement with a persistent hypointense central region on post-contrast (non-fat-suppressed) T1-weighted images that was hyperintense on T2-weighted images and was felt to represent necrosis,[4] most likely consistent with the fluid sign as described by Baur and colleagues.[8]

**Table 1** Various signs of benignity and malignancy in cases of vertebral collapse

| Signs Favoring Benignity | Signs Favoring Malignancy |
|---|---|
| Presence of normal fatty marrow | Absence of normal fatty marrow |
| Absence of multifocal involvement | Multifocal involvement |
| Absence of pedicle involvement | Pedicle involvement |
| Presence of fracture line | Absence of fracture line |
| Absence of convex cortical contour | Convex cortical contour |
| Absence of extraosseous soft tissue mass | Extraosseous soft tissue mass |
| Intravertebral fluid | Absence of intravertebral fluid |
| Posterior-angulated fragment | Absence of posterior-angulated fragment |
| Fragmentation | Absence of fragmentation |

Using time-intensity curves, intravenous contrast-enhanced dynamic magnetic resonance imaging (MRI) has shown some value in the evaluation of benign collapse.[21] A pattern of early rapid contrast wash-in (at 20-30 seconds) with a second rising slope (after 30 seconds) is more likely to occur in benign collapse (acute or chronic), but not as specific as it did occur in one case of noncollapsed malignancy.[21]

## Malignant Collapse

The most common cause of malignant collapse is metastatic disease, usually from breast carcinoma, bronchogenic carcinoma, prostatic carcinoma, or renal carcinoma.[4,5] Multiple myeloma or solitary plasmacytoma and lymphoma are less common.[4] Presence of a single vertebral collapse in a patient with known primary malignancy, eccentricity of the fracture, consequential lesions, eccentricity of soft tissue masses, atypical and consequential fractures all favor malignancy; however, these features are not always present.[1]

Like osteoporotic collapse, malignant collapse possesses the same signal characteristics of hypointensity on T1-weighted images, hyperintensity on T2-weighted images,[6] and enhancement on postcontrast images.[1,7] On T2-weighted images, 85% will show hyperintense or heterogeneous signal that involves most of the vertebral body. The pattern of signal intensity may vary, however. Shih and colleagues[12] describe the area of signal abnormality as ill-defined in 75% of cases and well-defined in 25%. Marrow replacement from tumor infiltration is usually complete[6,11,14] (Figs 7, 8, 9, 10, 11, and 12). There is complete marrow replacement because the vast majority of vertebral metastases will not fracture until there is complete tumor infiltration, thus causing structural bone weakening from destruction of trabeculae, cortex, or both.[3] Multiple lesions are found in approximately 63% to 88% of cases; however, multiple lesions may also occur in osteoporosis, although not as commonly[3,4,5,6] (Fig 12).

In up to one-third of cases, there is incomplete marrow replacement and a small area of preserved fatty marrow may be seen.[4,3,13,14] As this is very typical of osteoporotic vertebral collapse, the shape and configuration of the signal changes may help to distinguish the etiology of these lesions. In these atypical cases with preservation of normal fatty marrow, the pattern is usually round and focal in morphology,[3,4] and yet some may be incomplete and even band-like, a typical feature of osteoporotic collapse.[11]

Restoration of normal fatty marrow does not occur in malignant collapse. Instead signal intensity changes typically progress but may remain unchanged.[1,11] Frequently there are signal abnormalities in adjacent vertebrae, usually representing metastatic foci.[3,4,5,6] These metastatic foci are typically well-marginated, round lesions.[4,7]

Anterior[6] and posterior vertebral body bulging or convexity can be seen in 33% to 70% of malignant collapse cases.[4,10,14] The posterior-angulated fragment is not a feature of malignant collapse.[4,6] Unilateral or bilateral pedicle involvement is seen in 69% to 88% of cases[3,4,8,12,14] (Fig 9). In cases of pedicle involvement, 75% will have complete involvement[14] and approximately 55% will show pedicle expansion, a specific sign for malignancy[12] (Fig 10); 5% to 6% of pathologic collapse may exhibit the fluid sign, which is typically characteristic of benign osteoporotic collapse.[4,8]

**Figure 6** Kümmell's disease of the lumbar spine in a severely osteoporotic post-menopausal 60-year-old Vietnamese woman. Lateral radiograph shows intravertebral vacuum phenomenon in multiple collapsed vertebrae.

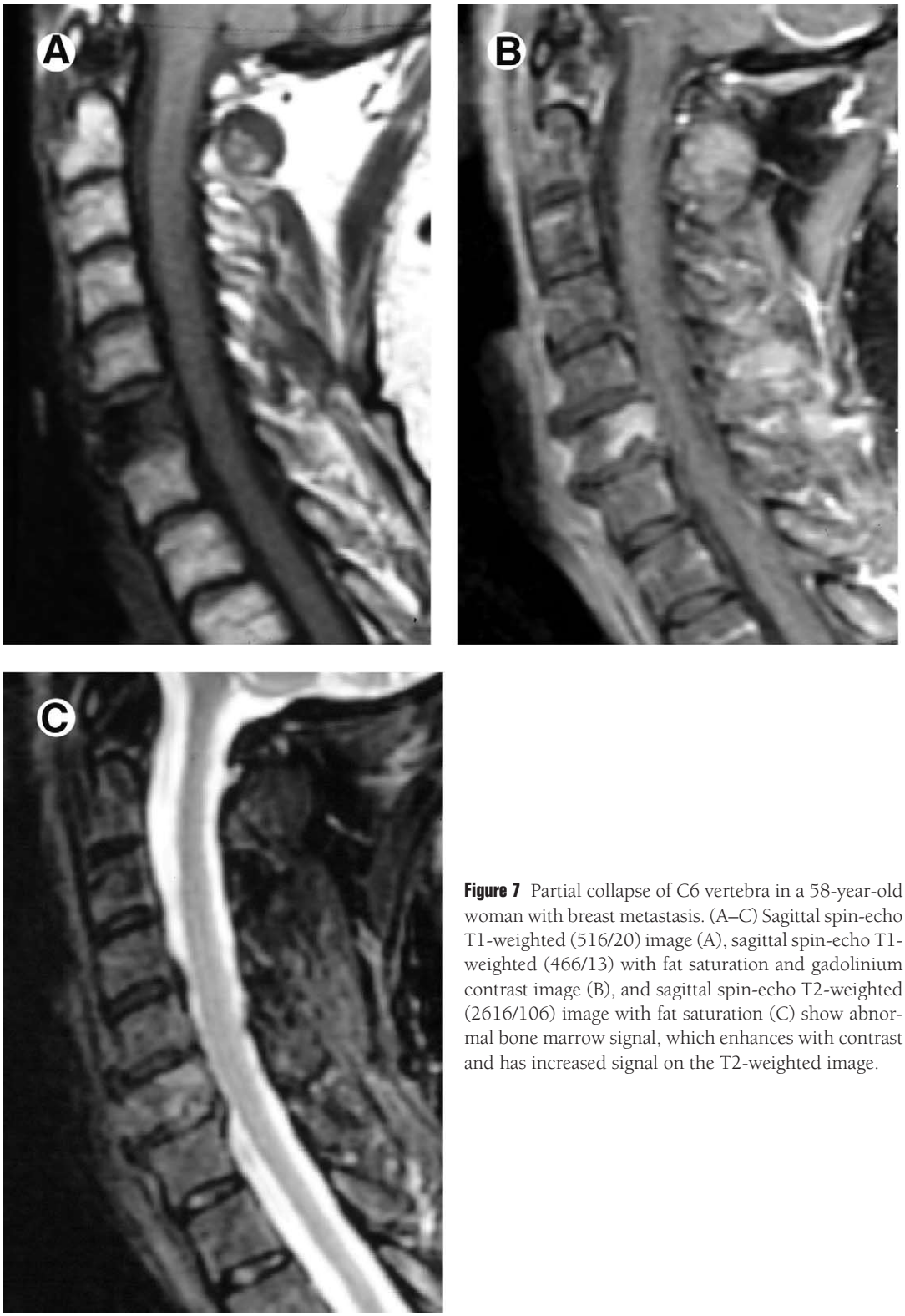


**Figure 7** Partial collapse of C6 vertebra in a 58-year-old woman with breast metastasis. (A–C) Sagittal spin-echo T1-weighted (516/20) image (A), sagittal spin-echo T1-weighted (466/13) with fat saturation and gadolinium contrast image (B), and sagittal spin-echo T2-weighted (2616/106) image with fat saturation (C) show abnormal bone marrow signal, which enhances with contrast and has increased signal on the T2-weighted image.

Cortical destruction was once thought to be a characteristic feature[7]; however, this is a nonspecific finding occurring in only half of solitary cases of malignant collapse.[12] The same percentage is seen in cases of solitary benign collapse.[12]

Paraspinal and/or epidural soft tissue masses are more characteristic features.[7] Paraspinal and/or epidural masses are visualized in 47% to 100% of patients with malignant collapse[5,14] (Figs 10 and 11). Larger, well-defined soft tissue masses are more likely to be malignant than smaller, poorly defined masses.[1] In the study of Shih and colleagues,[12] a thin rim-shaped paraspinal soft tissue lesion was described in 75% of solitary malignant collapse and an irregular nodular

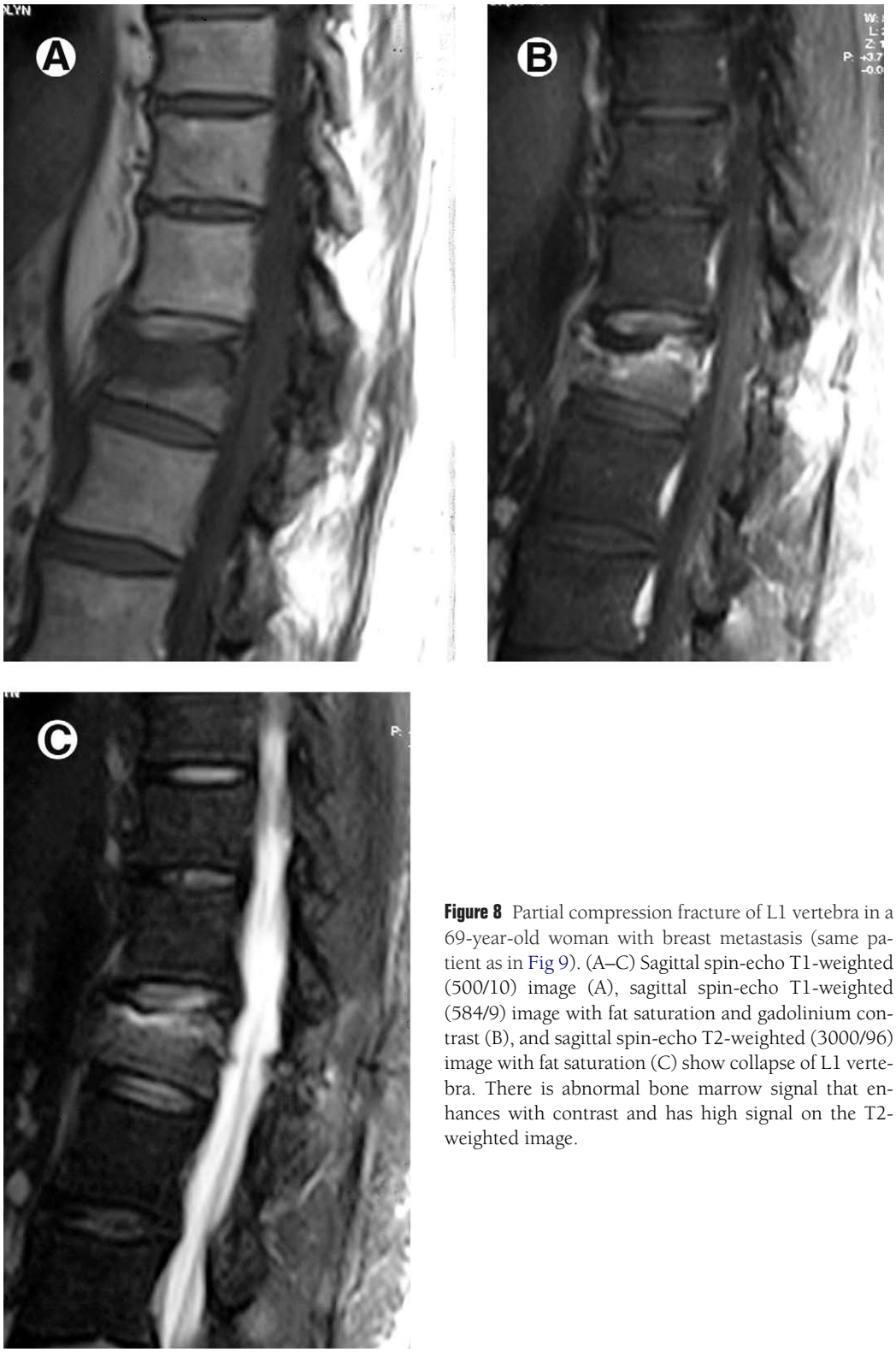


**Figure 8** Partial compression fracture of L1 vertebra in a 69-year-old woman with breast metastasis (same patient as in Fig 9). (A–C) Sagittal spin-echo T1-weighted (500/10) image (A), sagittal spin-echo T1-weighted (584/9) image with fat saturation and gadolinium contrast (B), and sagittal spin-echo T2-weighted (3000/96) image with fat saturation (C) show collapse of L1 vertebra. There is abnormal bone marrow signal that enhances with contrast and has high signal on the T2-weighted image.

paraspinal soft tissue lesion in the remaining 25%. Epidural extension is seen in 11% to 80% of cases.[4,10,13]

Since most vertebral metastasis occur hematogenously, there is absence of involvement of the avascular regions of the cartilaginous endplate and disks.[1] In primary malignant vertebral involvement, however, there may be endplate and disk abnormality mimicking infection.[1]

The "return to normal" signal intensity as seen in osteoporotic collapse on post-contrast non-fat-suppressed T1-weighted images is not usually seen in malignant collapse

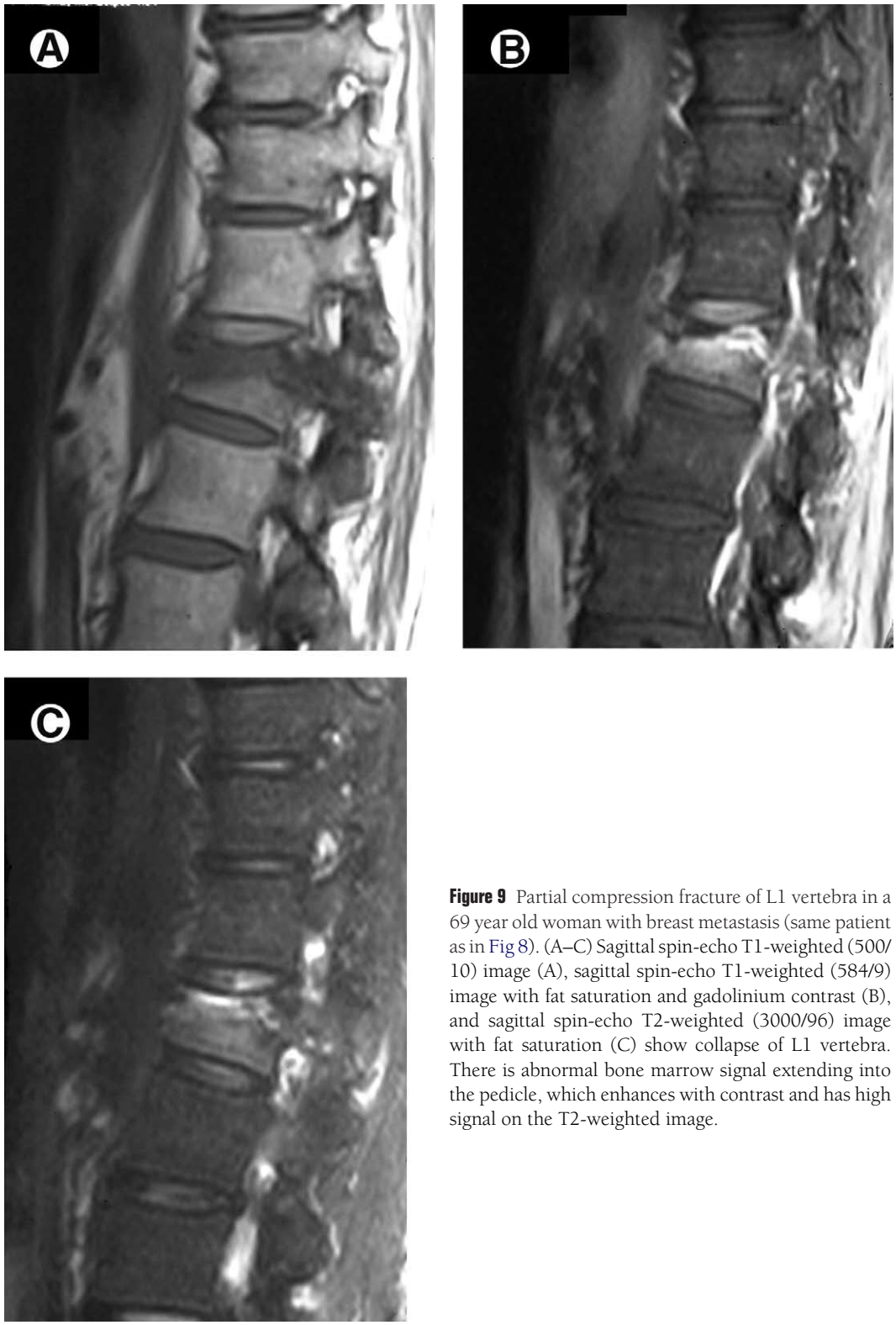


**Figure 9** Partial compression fracture of L1 vertebra in a 69 year old woman with breast metastasis (same patient as in Fig 8). (A–C) Sagittal spin-echo T1-weighted (500/10) image (A), sagittal spin-echo T1-weighted (584/9) image with fat saturation and gadolinium contrast (B), and sagittal spin-echo T2-weighted (3000/96) image with fat saturation (C) show collapse of L1 vertebra. There is abnormal bone marrow signal extending into the pedicle, which enhances with contrast and has high signal on the T2-weighted image.

cases.[4] Enhancement is typically heterogeneous or hyperintense with diffuse or patchy distribution and without any linear regions.[4] Use of postcontrast images has been shown to have 100% sensitivity in one small study.[5] Intense or marked heterogeneous enhancement is observed in 94% (15 of 16 cases) of solitary malignant vertebral collapse.[12] The heterogeneity of enhancement is most likely due to uneven blood supply and/or tumor necrosis.[12] Homogeneous and mild enhancement is seen in only 6% (1 of 16 cases) of cases in the same study.[12]

Intravenous contrast-enhanced dynamic MRI with time-intensity curves has shown some value in the evaluation of


**Figure 10** Partial collapse of T11 vertebra in a 50-year-old Arab man with gastric metastasis (same patient as in Figs 11 and 12). (A–C) Sagittal spin-echo T1-weighted (500/10) image (A), sagittal spin-echo T1-weighted (615/9) image with fat saturation and gadolinium contrast (B), and sagittal spin-echo T2-weighted (3000/96) with fat saturation image (C) show partial collapse of T11 vertebra with abnormal signal in the bone marrow, which enhances with contrast and is increased signal on the T2-weighted image. Note the pedicle involvement and large soft tissue mass that extends into the spinal canal and intervertebral foramen.

malignant lesions, with and without collapse.[21] A pattern of rapid contrast wash-in (20-30 seconds) followed by early washout (up to 180 seconds) is specific for differentiating metastatic disease from benign collapse; however, since this pattern of enhancement was found only in approximately one-third of malignant vertebral lesions, the sensitivity is low. Most malignant collapses demonstrated a pattern of rapid wash-in followed by a plateau after peak enhancement, which is a nonspecific finding.[21]

Osteoblastic metastatic foci are usually not a dilemma as they can be detected on radiographs or CT examination. On MR imaging, they possess low signal on all pulse se-

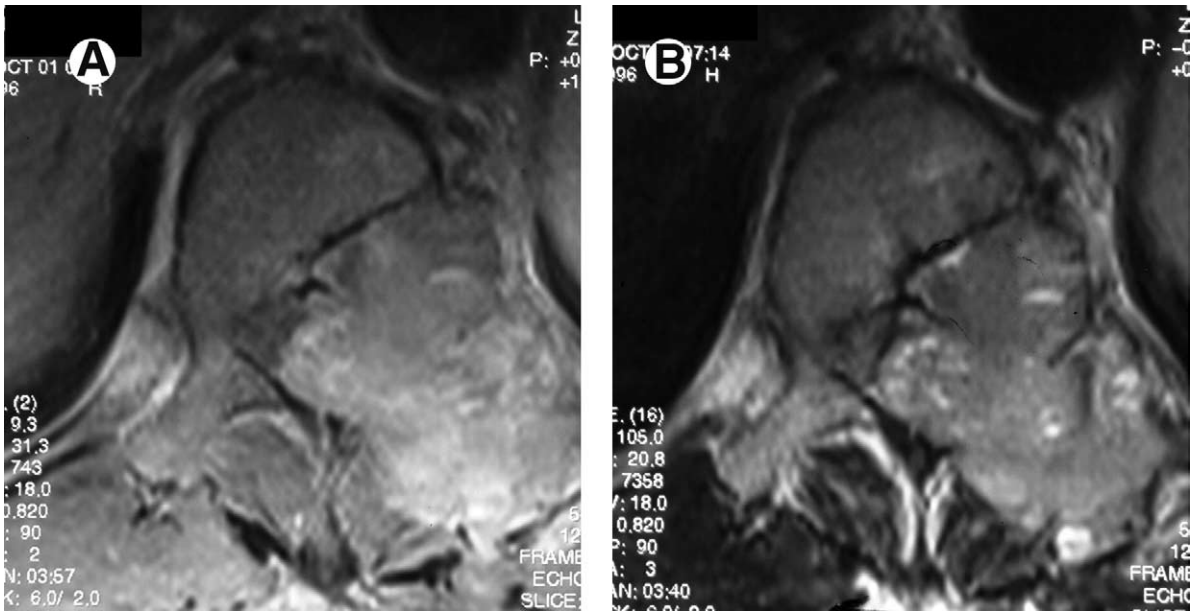


**Figure 11** Vertebral metastasis in a 50-year-old man with gastric carcinoma (same patient as in Figs 10 and 12). (A and B) Axial spin-echo T1-weighted (753/9) image with fat saturation and gadolinium contrast (A) and axial spin-echo T2-weighted (7358/105) image with fat saturation (B) show a large soft tissue mass extending into the vertebral body, posterior elements, and spinal canal on the left side.

quences.[8,13,22] However, multiple small foci of enhancement may sometimes be noted on postcontrast images, due to small osteolytic changes that are frequently hidden by the blastic component.[7]

Vertebral collapse due to multiple myeloma and/or plasmacytoma deserves special attention. Myelomatous collapse frequently do not demonstrate the complete marrow replacement commonly seen in malignant collapse.[1,5,23] In newly diagnosed multiple myeloma, up to 20% will have normal bone marrow and over half have multiple fractures.[24] Of the patients with multiple fractures, only 46% will have an associated soft tissue mass.[24] In a study by Cuénod and colleagues,[4] three cases of myelomatous collapse displayed homogenous hyperintensity on T2-weighted and post-contrast fat saturated T1-weighted images. In a study including 37 patients with biopsy-proven stage III multiple myeloma and 224 cases of vertebral collapse, Lecouvet and colleagues[23] observed benign-appearing vertebral collapse in 67% of cases. Even if preexisting cases of collapse are excluded, 59% of cases still had benign-appearing characteristics. In 14 patients (38%), only benign-appearing collapses were evident (no malignant characteristic). In addition, the sclerotic form of myeloma may have atypical findings, including hypointensity on T1-weighted images, isointensity on T2-weighted images, and lack of enhancement on post-contrast images.[4]

## Infectious Collapse

Osteomyelitis involving the vertebral body with resultant collapse is not as common as collapse due to osteoporosis or malignancy. However, it can occur in primary cancer patients who may be immunocompromised and thus more susceptible to infection. Because of the similar patient population, an infectious etiology must be considered in these cases. In the United States, the most common infectious organism is *Staphylococcus aureus* (Fig 13). *Streptococcus*, *Staphylococcus epidermidis*, and *Mycobacterium tuberculosis* are some of the other more frequent pathogens.[25]

Patients with vertebral osteomyelitis frequently have had prior infections that were incompletely treated with antibiotics.[1] However, in approximately one-third of patients, no primary source of infection can be identified.[1] Although clinical findings of fever and increased white blood cell (WBC) count often secure the diagnosis, one or both of these findings are not present in at least half of patients with vertebral osteomyelitis.[26]

Vertebral osteomyelitis typically does not pose a problem in MR imaging diagnosis because there are usually characteristic features. MR imaging provides high sensitivity (96%), specificity (92%), and accuracy (94%) in the diagnosis of vertebral osteomyelitis.[27] In descending order of sensitivity, findings suggestive of infectious collapse include paraspinal or epidural mass enhancement, disk enhancement, disk hyperintensity on T2-weighted images, and disruption of the cartilaginous endplate on T1-weighted images.[28] Other findings may include hypointensity of adjacent endplate and vertebral body on T1-weighted images, hyperintensity on T2-weighted images of the endplate and vertebral body on post-contrast images.[1,7,25,27,29] This appearance, however, may be similar to that encountered in benign traumatic vertebral collapse[1] (Figs 3 and 4).

Absence of the nuclear cleft was not useful in this study.[28] This sign was not applicable in 26 of 44 cases, as the nuclear cleft was not seen in adjacent, normal disks. Additionally, it


**Figure 12** Partial collapse of T11 and L2 vertebrae in a 50-year-old man with gastric metastasis (same patient as in Figs 10 and 11). (A–C) Sagittal spin-echo T1-weighted (600/10) image (A), sagittal spin-echo T1-weighted (615/9) image with fat saturation and gadolinium contrast (B), and sagittal spin-echo T2-weighted (3000/96) image with fat saturation (C) show partial collapse and abnormal marrow signal of T11 and L2 vertebrae. Note lesion multiplicity and soft tissue extension into spinal canal and posterior elements at T11.

provided false-negative results in three cases.[28] Decreased disk height and disk hypointensity on T1-weighted images were not found to be sensitive for diagnosis of vertebral osteomyelitis.[28]

There are atypical cases that have little or no involvement of the endplate, and in a cancer patient with recent onset low back pain, an incorrect presumptive diagnosis may be made and thus inappropriate therapy rendered.[7] Disk involvement may be absent in up to 10% of vertebral osteomyelitis (with or without collapse).[30] In the review of pyogenic vertebral collapse without disk involvement by Abe and colleagues,[26] the distribution of pathogens was similar to that of typical

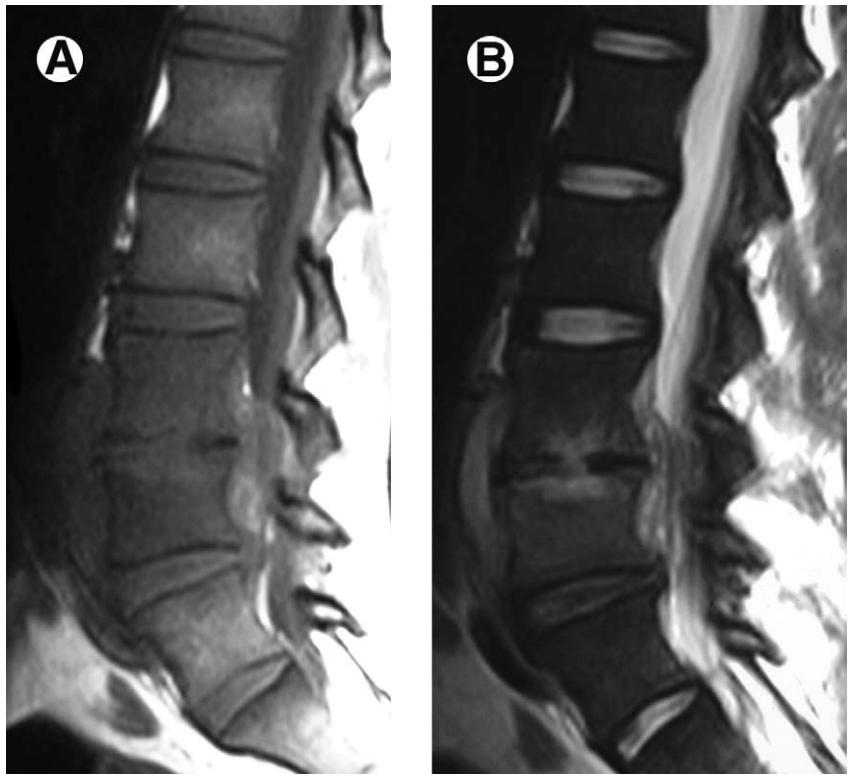


**Figure 13** *Staphylococcus aureus* spondylitis in a 30-year-old Latino man with 1 month history of low back pain. (A and B) Sagittal spin-echo T1-weighted (457/10) image with fat saturation (A) and sagittal spin-echo T2-weighted (2500/80) image with fat saturation (B) show the cortical endplate resorption and anterior soft tissue abscess or phlegmon with bright signal on T2-weighted image. The marrow signal is abnormal at L4 and L5 vertebrae.

vertebral osteomyelitis, with *Staphylococcus aureus* being the most common pathogen.

The posterior elements are typically uninvolved in infections, but facet involvement occasionally may occur by contiguous spread or rarely, as a primary site of septic arthritis.[1]

In the study by Dagirmanjian and colleagues,[25] 43% (10 of 23) did not show hyperintensity of the adjacent vertebral body on T2-weighted images. The authors explain this partly by the presence of sclerosis as noted on radiographs. In younger patients, where there is still vascular communication with the disk, localized diskitis may occur, without involvement of the adjacent vertebrae.[27] This situation is rarely seen in older patients.[27]

Epidural abscesses are usually isointense to the spinal cord on T1-weighted images, and hyperintense on T2-weighted images. However, they may have a varied appearance, including heterogeneous mixed intensities on both T1- and T2-weighted images.[27] Use of contrast provides additional confidence in the diagnosis of vertebral osteomyelitis. Intense enhancement of the disk, adjacent vertebral bodies, abscesses, and phlegmon are almost always noted.[27,28] Intense enhancement of the disk and adjacent vertebral endplate and body are particularly helpful in strengthening the diagnosis of vertebral osteomyelitis.[27] Paraspinal soft tissue masses, when seen, are usually large with poorly defined margins and surround the disk symmetrically.[1] Asymmetric soft tissue masses may suggest tuberculous origin but may further complicate the diagnosis, as malignant collapses frequently also have asymmetric soft tissue paraspinal masses.[1]

Intravenous contrast administration is crucial in the diagnosis of infectious collapse. Enhancement can vary from thick and patchy to thin linear enhancement. Enhancement at the periphery of the disk may be thick or thin and continuous or discontinuous.[25,29] The adjacent vertebral bodies also enhance to varying degrees.[25] Most importantly, some degree of enhancement of the disk and adjacent vertebral bodies is a consistent finding.[25]

Osteomyelitis due to tuberculosis remains a public health hazard, especially in the growing HIV-positive population,[31] homeless individuals, and expanding immigrant population.[32] An accurate diagnosis is imperative, as up to 10% of patients experience serious complications such as paraplegia and even quadriplegia.[31]

Tuberculous spondylitis usually occurs via hematogenous spread and is initially located at the anterior discovertebral junction.[27] The thoracolumbar region is most commonly affected (Fig 14) and typically tuberculous spondylitis involves more vertebrae than pyogenic spondylitis. Hypointensity on T1-weighted and hyperintensity on T2-weighted images in the vertebrae and associated paraspinal soft tissue masses and a decreased disk height is typical.[32,33] Unlike pyogenic osteomyelitis, the disk space is sometimes preserved. The developing inflammatory process may erode cortical bone, destroy the disk, involve the adjacent vertebral body, and, less commonly, the posterior elements.[27] Subligamentous spread (usually the anterior longitudinal ligament but can be the posterior longitudinal ligament) and paraspinal or epidural extension[32] and development of paraspinal abscess below the level of spondylitis, especially in the psoas muscle, are commonly seen and are frequently bilateral.[1,27] In severe cases of vertebral collapse, an angular kyphosis or gibbus deformity may develop.[27] Hyperintensity in the cord on T2-weighted


**Figure 14** Tuberculous spondylitis and vertebral collapse in a 40-year-old woman. (A–C) Sagittal spin-echo T1-weighted (450/16) image (A), sagittal spin-echo T1-weighted (466/13) image with fat saturation and gadolinium contrast (B), and sagittal spin-echo T2-weighted (2600/110) image with fat saturation (C) show collapse and spondylodiscitis of the thoracolumbar vertebrae with gibbus deformity and retropulsion into the spinal canal. Note abnormal signal, which has relatively intense rim enhancement on T1-weighted post-contrast image and intermediate signal on T2-weighted image.

images may indicate a poor prognosis.[1] Multifocal spine involvement, or skip lesions, have been described and this may be easily confused with vertebral metastasis.[27]

Paraspinal and epidural extension are more common in tuberculous spondylitis versus pyogenic spondylitis.[30] A thick rim of enhancement has been used to differentiate tuberculous spondylitic abscesses from other granulomatous infections.[32] Interestingly, Sharif and colleagues[33] report vacuum disk phenomena, a characteristic feature of degenerative or traumatic disk disease, in 5 of 17 patients with brucellar spondylitis. Unfortunately, there are no pathognomonic imaging signs that allow tuberculosis to be readily distinguished from other conditions.[31]

## Differentiating Osteoporotic, Pathologic, and Infectious Vertebral Collapse on Conventional MR Imaging

Using conventional MR imaging, a diagnostic accuracy of 79% to 94% seems plausible.[3,4,6,14] Determining whether an acutely

**Table 2** Characteristic imaging findings of osteoporotic, malignant, and infectious vertebral collapse

| Highly predictive findings | | |
|---|---|---|
| **Osteoporotic** | **Malignant** | **Infectious** |
| Restoration of normal fatty marrow | Complete involvement of one or both pedicles with or without expansion | Intense enhancement of disc |
| Restoration of normal signal intensity on T2-weighted images | Nodular, irregular paraspinal extension | Presence of and intense enhancement of paraspinal and/or epidural extension |
| Posterior-angulated fragment | | |
| Fragmentation | | Intense enhancement of endplate and adjacent marrow |
| **Fairly predictive findings** | | |
| Band-like hypointensity on T1-weighted images | Complete marrow replacement | Hyperintense disc on T2-weighted images |
| Incomplete marrow replacement | Posterior vertebral body convexity | Destruction of endplate on T1-weighted images |
| Intravertebral fluid (vacuum) sign on T2-weighted images | Well-defined round foci in other vertebrae | Hyperintensity on DWI** |
| Absence of epidural extension | Epidural soft tissue extension* | Low ADC** |
| Absence of disc involvement | Hyperintensity on DWI* | |
| Rapid wash-in and second slow-rising slope on dynamic contrast-enhanced imaging | Low ADC* | |
| Hypointensity on DWI | | |
| High ADC | | |

*This finding favors malignant over osteoporotic, but not infectious collapse.
**This finding favors infectious over osteoporotic but not malignant collapse. DWI = diffusion-weighted imaging; ADC = apparent diffusion coefficient.

collapsed vertebra is due to osteoporosis based solely on imaging findings may be difficult because of its varied appearance.[1,3,4,6,8-11] There are several features that are highly specific of osteoporotic collapse. When seen independently, restoration of normal fatty marrow,[5,6,7,11,15] restoration of normal signal intensity on T2-weighted images[1,6] (from hyperintense to isointense), the posterior-angulated fragment,[4,6,7] and fragmentation[3] are highly predictive of benign osteoporosis as the etiology. Please note that fragmentation and the posterior-angulated fragment have low sensitivity because their occurrence is uncommon (Tables 1 and 2).

Features of good specificity include a band-like hypointensity adjacent to the fractured endplate or incomplete marrow replacement,[4,5,14] an intravertebral fluid (or vacuum) sign,[4,8,9,18] absence of an epidural soft tissue mass,[4,5,10,13] lack of disk involvement, and, using time-intensity curves with dynamic contrast-enhanced MRI, a pattern of rapid wash-in with a second slow-rising slope.[21]

In attempting to predict collapse due to malignancy, complete involvement of the pedicles, with or without expansion of the pedicles[3,4,8,12,14] and a nodular, irregular paraspinal soft tissue lesion[12] are the only highly specific indicators. Characteristics demonstrating good specificity include complete marrow replacement,[6,11,14] posterior vertebral body convexity or bulging,[4,10,14] and well-defined foci of signal abnormality in multiple vertebrae.[3-6] Epidural soft tissue extension helps to differentiate malignancy from osteoporosis, but not from infection.[4,10,13,27,28]

Collapse due to osteomyelitis must be evaluated with intravenous contrast administration.[27] Intense enhancement of the disk, presence of and intense enhancement of paraspinal and/or epidural soft tissue masses, especially ring-enhancement indicative of abscess, and intense enhancement of the disk and adjacent vertebral endplate and body are particularly helpful in strengthening the diagnosis of vertebral osteomyelitis.[27,28]

## Diffusion-Weighted Imaging

Diffusion-weighted imaging (DWI) observes the stochastic micromolecular (Brownian) motion of water[42] (Fig 15). In acute stroke and in brain tumors, there is restricted motion of water resulting in hyperintensity on DWI and hypointensity on apparent diffusion coefficient (ADC) maps.[7] These findings may be used to quantify and characterize the variable changes in the micromolecular motion of water. ADC mapping is valuable by eliminating T2 shine-through artifact, and thus shows true diffusion findings[7] (Figs 16 and 17). DWI is also useful in the assessment of response to therapy in cases of metastatic disease.[22] Conversely, DWI in the acute diagnostic phase is limited to patients who have not received radiation therapy.[22]

The initial spin-echo technique (SE) for DWI measured intravoxel incoherent motion.[34] Disadvantages of this method center around its long acquisition times, which increase its susceptibility to motion artifact.[34] Pulse triggering can be used to reduce motion artifact, but the exam time remains essentially the same.[34]

Some authors believe that some DWI techniques, such as

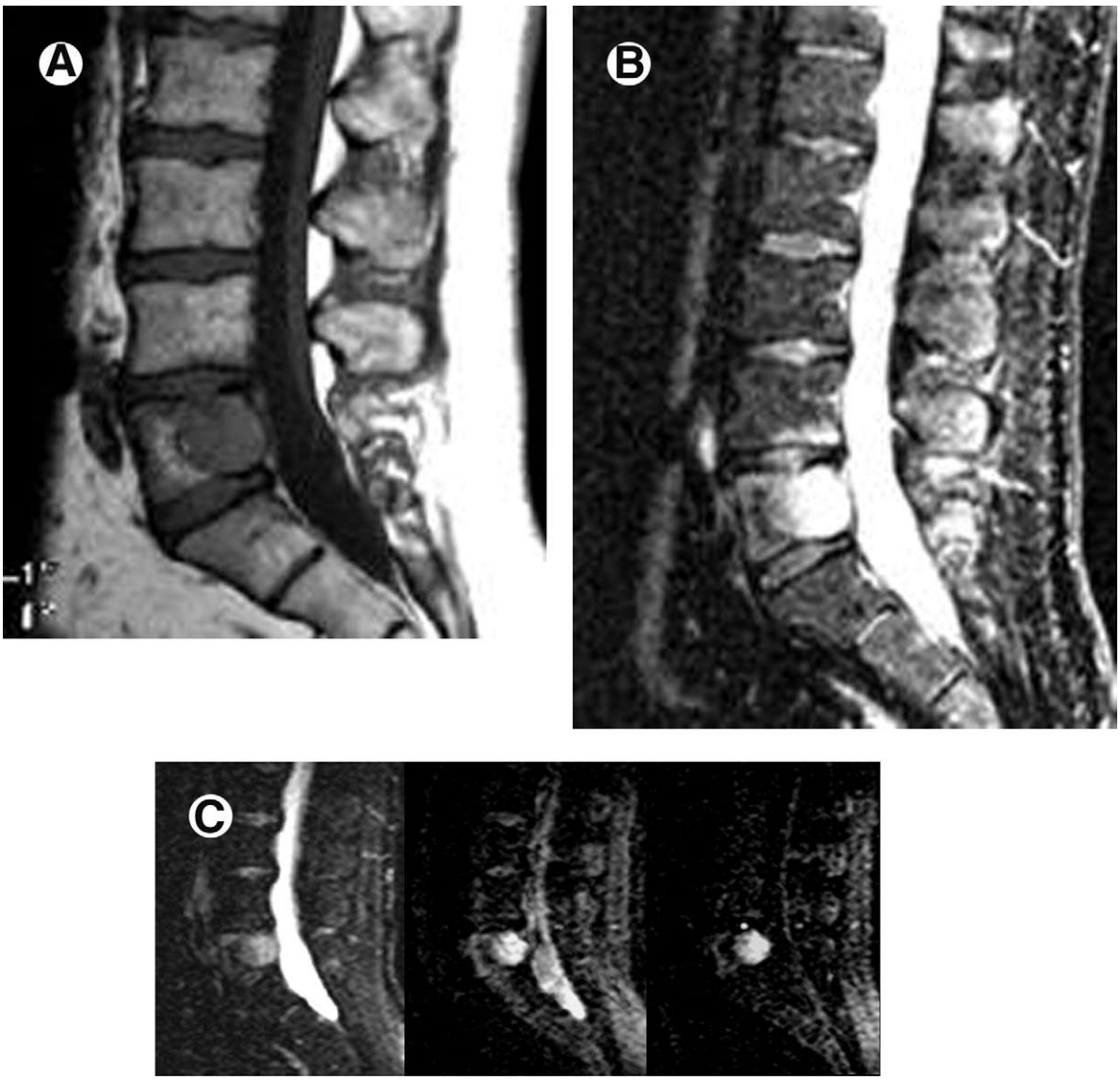


**Figure 15** Vertebral metastasis in a 47-year-old man with squamous cell carcinoma of the lung (courtesy of Dr. Andreas M. Herneth, Vienna, Austria). (A–C) Sagittal spin-echo T1-weighted image (A) shows intermediate to low signal intensity mass in posterior body of L5 vertebra. Sagittal spin-echo STIR (short tau inversion recovery) image (B) shows the mass as a bright signal. Sagittal navigated DWI (diffusion-weighted image) (C) also shows bright signal in the region of metastasis. Note posterior cortical bulging, which is a sign of malignancy.

single-shot echo-planar imaging (EPI) may not be useful for spinal imaging because of the heterogeneous magnetic environment and the high lipid content of the vertebrae can lead to strong geometric distortions and chemical shift artifact.[34,35] However, such technical constraints have been at least partially overcome by improvements in hardware components, with the use of navigated echoes, or with the use of multishot EPI.[34,47] EPI, is in some authors' opinion, the study of choice for producing ADC values.[38]

DWI of the spine was introduced by Baur and colleagues[11] who observed isointensity or hypointensity on DWI in all benign vertebral collapse and hyperintensity in all pathologic vertebral collapse. The hypointensity on DWI in benign collapse is thought to be due to the increase in free water in bone marrow from edema and hemorrhage, which leads to an increase in the extracellular volume fraction.[11] Extracellular water protons are known to be the main contribution to the ADC.[11] Conversely, in malignant collapse the decrease of extracellular volume due to tumor infiltration might lead to a reduction in ADC.[11] Several other institutions published similar studies, however, with conflicting results.[39-41] In the study by Castillo and colleagues[40] 9 of 15 patients had purely blastic metastasis and 2 patients had previously undergone long-term radiation therapy, which might at least partly explain their contrasting data.[42] It is well known that osteoblastic metastases and previous radiated metastases exhibit low signal on DWI.[13,22,42] Therefore the indication for DWI should be findings on radiographs, CT, and conventional MR imaging that complicate the distinction between benign and malignant vertebral collapse.[34,42]

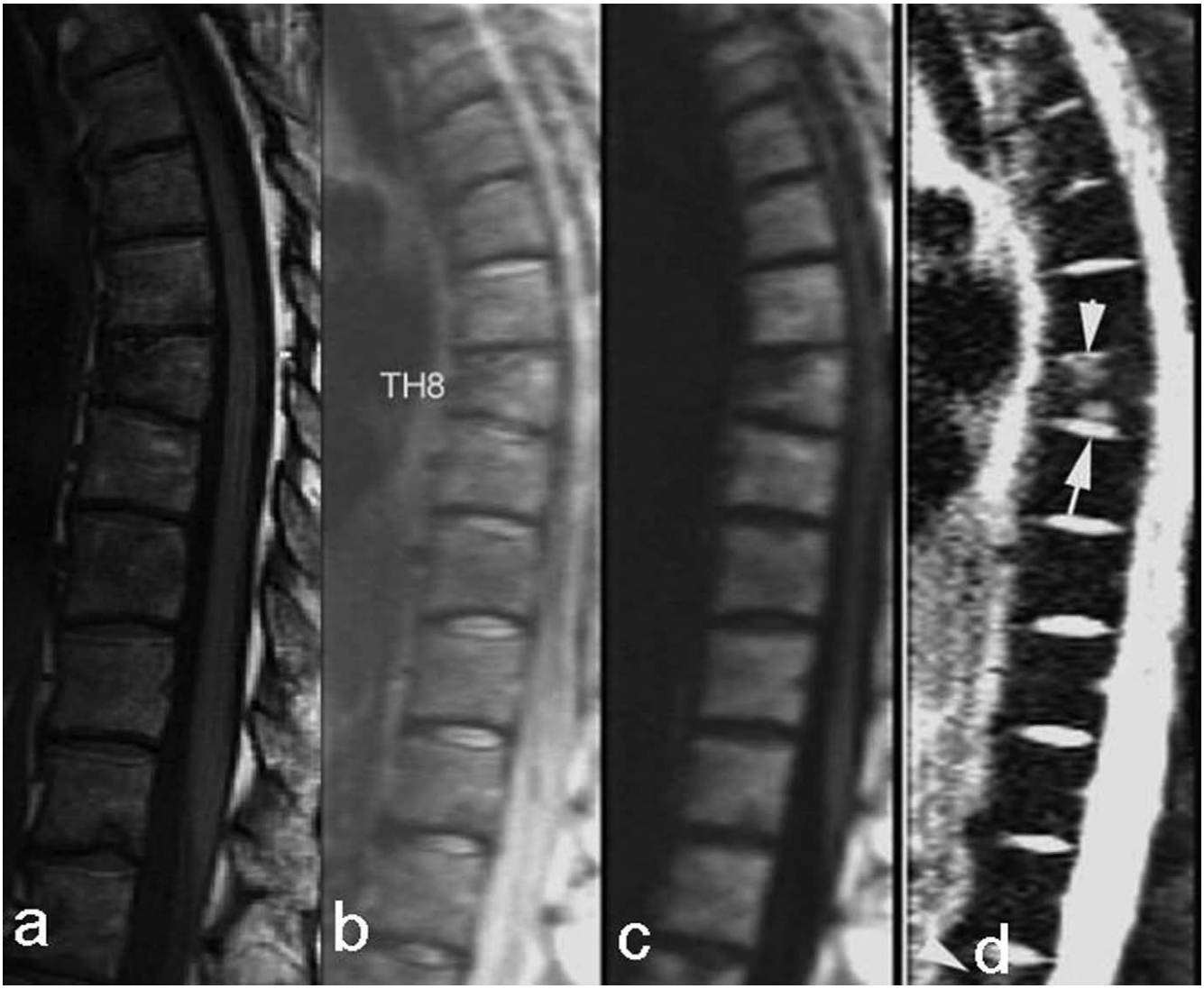


**Figure 16** Traumatic compression of T8 vertebra in a 65-year-old woman with breast carcinoma and history of trauma (courtesy of Dr. Andreas M. Herneth, Vienna, Austria). (A–C) Sagittal spin-echo T1-weighted image (A) shows compression and minimal low signal intensity at the anterior aspect of T8 vertebra. Sagittal spin-echo T2-weighted image (B) shows relatively low signal in the vertebral body. Sagittal EPI (echo planar imaging) DWI (diffusion-weighted image) (C) also shows low signal intensity at T8 vertebra. Sagittal ADC (attenuated diffusion coefficient) image (D) shows bright signal of partially compressed T8 vertebra indicating no sign of metastasis.

Critics of Baur's original study center on the steady-state free precession (SSFP) diffusion technique used in the study. SSFP generates the DWI from both T1 and T2 effects, and thus is susceptible to T2 shine-through artifact and therefore may not represent a true diffusion-weighted image.[43] Therefore benign collapse with hyperintensity on T2-weighted images with resultant hyperintensity on DWI may be a false-positive.[7] In these cases, ADC maps are critical in determining the water content of a benign, osteoporotic collapse.

However, in the initial study of Baur and colleagues,[11] they used a time-reversed fast imaging sequence (PSIF) based on SSFP to produce diffusion-weighted images, which overcame many of the problems that prevent the performance of satisfactory EPI-DWI in the spine.[20] With this SSFP technique, however, quantitative (ADC) analysis is a highly complex calculation and technically not possible.[44] When malignant lesions are hypointense on DWI, ADC mapping is able to suggest malignancy.[7]

SSFP-DWI was also used with increasing diffusion-weighting to help evaluate acute vertebral collapse.[36] The diffusion-weighting was increased from a diffusion pulse length ($\delta$) of 0.6 ms to 3.0 ms, 6.0 ms, and 9.0 ms. At $\delta = 3.0$ ms, 13 of 15 osteoporotic collapse cases were isointense or hypointense. The remaining two were hyperintense. There is no reasonable explanation for hyperintense signal in osteoporotic vertebrae on DWI and the authors propose that perhaps there are different subtypes of bone marrow edema and that higher diffusion weighting is necessary to achieve a significant signal loss.[36] This is partially supported by all isointense and hyperintense cases becoming hypointense at $\delta = 6.0$ ms, except for one case that remained isointense. Other effects such as T2

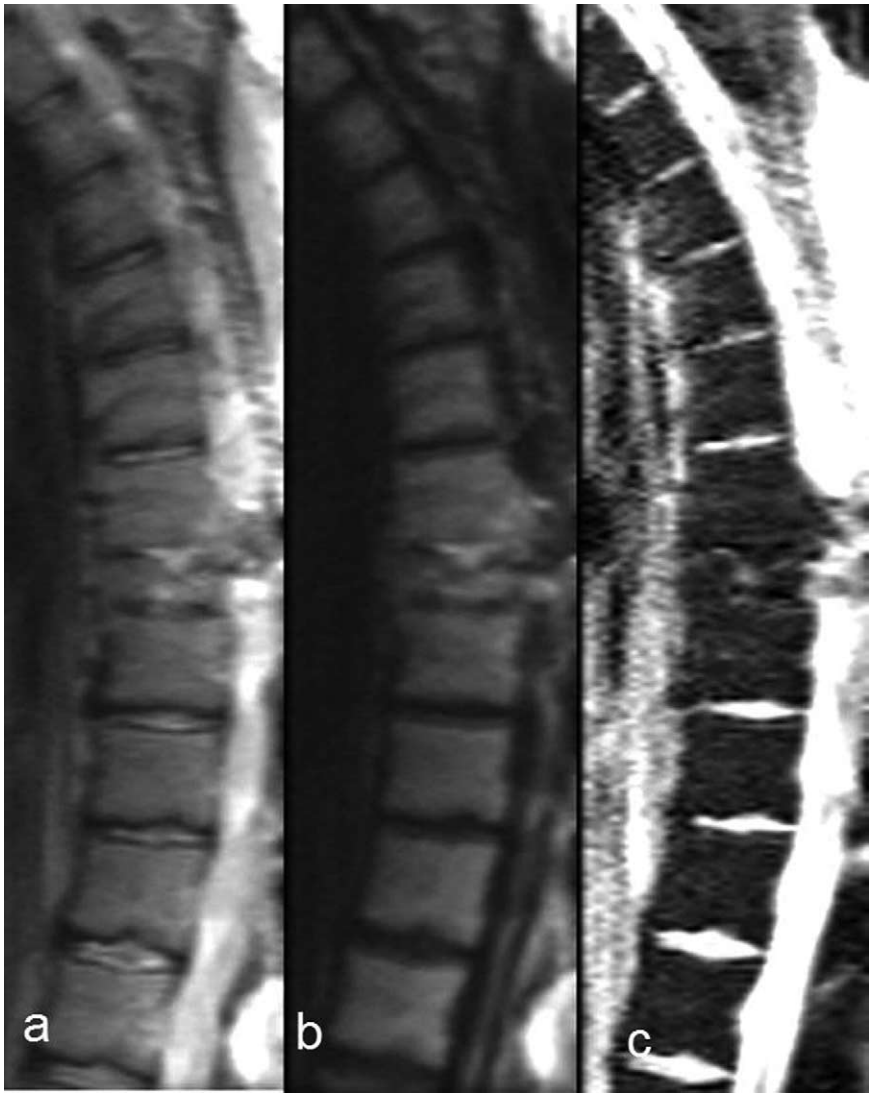


**Figure 17** Metastasis to thoracic vertebra in a 57-year-old man with a history of prostate carcinoma and acute trauma (courtesy of Dr. Andreas M. Herneth, Vienna, Austria). (A–C) Sagittal spin-echo T2-weighted image (A) shows compression and mixed bright signal lesion posteriorly in a mid-thoracic vertebra. Sagittal EPI (echo planar imaging) DWI (diffusion-weighted image) (B) shows compression and mixed bright signal of mid-thoracic vertebra. Sagittal ADC (attenuated diffusion coefficient) image (C) shows low signal at site of metastasis.

shine-through, extensive fibrosis, or excessive bleeding may also have a factor in these false-positive cases.[45] In the malignant collapse group, all demonstrated hyperintensity at both $\delta = 3.0$ ms and $\delta = 6.0$ ms sequences (15 of 16 were of marked hyperintensity).[36] Therefore, increasing diffusion-weighting with SSFP-DWI appears to be useful.

Spuentrup and colleagues[46] prospectively evaluated spin-echo, stimulated echo, and fat-suppressed spin-echo DWI on 18 acute osteoporotic collapse and 17 malignant vertebral lesions, including 9 with collapse. The findings demonstrated that all three techniques were equally suitable for imaging of the spine, and provided differentiation of osteoporotic collapse and malignant collapse.[46] The authors cite a few cases where DWI changed the diagnosis (and thus treatment) from a previous diagnosis rendered from the conventional MR images. Quantitative evaluation was not performed in this study.

Zhou and colleagues[39] developed and used a fast spin-echo pulse sequence with single-shot and multiple signal acquisitions to assess quantitative diffusion imaging of osteoporotic and malignant collapse. Overlapping findings were noted in all conventional MR (T1-, T2-weighted, post-contrast images), and diffusion-weighted imaging. ADC values showed significant differences in the two groups. While the histograms for osteoporotic and malignant lesions overlapped, the authors, after a two-tailed *t* test, contend that they belong to two distinct distributions.[39]

Using single-shot echo-planar pulse sequence for DWI, Chan and colleagues[13] showed significantly different ADC values and observed no overlap between absolute ADC values for benign and malignant vertebral collapse. In addition, hypointensity in all acute benign collapse and hyperintensity in all malignant collapse on DWI was demonstrated. Since single-shot echo planar is known for its sensitivity to magnetic susceptibility artifacts with resultant image distortion, the authors used a fat-suppression technique. However, two cases of collapse due to tuberculous spondylitis (which, based on the conventional MR images, were diagnosed as malignant collapse) possessed similar ADC values as the malignant cases.[13] Therefore, in this study, ADCs were unable to differentiate malignant collapse from infectious (tuberculous) collapse.

Herneth and colleagues[37,47] used EPI-DWI and calculated absolute ADC values with navigated echoes and fat saturation (Figs 15 through 17), and they showed that the mean ADC of normal vertebral marrow and marrow of osteoporotic collapse were significantly higher than marrow from metastatic cases (with and without collapse). More important, there was no overlap of absolute values between the two groups.[37,47] ADC parameters were a reliable method to distinguish vertebral metastasis from normal and benign collapse vertebrae.[47] The authors, however, note their preference in the use of pixel-by-pixel quantitative analysis rather than the image assessment via ADC maps.[47] Other similar studies have shown contrasting results, however.[42]

There is limited literature in the application of DWI to cases of suspected infectious vertebral collapse. In one study[13] (mentioned above), two cases of tuberculous collapse were originally interpreted as malignant collapse on DWI. The diagnosis of tuberculosis was suggested only after biopsy was performed. Other authors also suggest that infectious spondylitis should be taken into account when hyperintense signal is shown on DWI.[42,45] Morphology and distribution of infectious spondylitis are usually, but not always, different from metastatic disease.[42]

In a case report of vertebral collapse due to infection with vertebral and epidural abscesses,[48] a DWI was generated by spin-echo-planar technique with navigator echo motion correction (to correct for phase errors due to motion). In this patient with bacteremia, DWI displayed marked hyperintensity and increased the conspicuity of the lesion when compared with conventional T1-, T2-weighted, and postcontrast images.[48] ADC maps displayed a corresponding hypointensity in the same region, which is consistent with abscesses in other parts of the body, namely in the brain and liver.[48] Absolute ADC calculation was not performed in this case because of the small region of interest was assumed to be prone to volume-averaging effects.

Line-scan DWI is a technique that has shown encouraging results.[35,43] Line scan DWI is inherently less sensitive to motion than regular 2D Fourier imaging techniques and is able to produce diffusion maps without the use of restraining or gating mechanisms.[35] It also does not require high slew rate (rate at which a magnetic gradient field can be changed to different field strengths) gradient hardware and can be implemented on systems with conventional gradient hardware.[35]

The study by Maeda and colleagues[41] used line-scan DWI for both qualitative and quantitative analysis. They found no significant difference in qualitative DWI analysis between benign and malignant collapse.[41] In addition, while their mean ADC values were significantly different, there was a considerable amount of overlap.[41] The authors suggest three possible reasons for these results: First, the presence of necrotic tissue can increase the ADC and this may have influenced their results. Second, it is possible that a larger fraction of associated bone marrow edema was used in the calculation, thereby increasing the ADC value. Third, hypervascularity of the malignant tumors proportionately increases perfusion and this elevates the ADC value as well.

It is not known why there are such contrasting results in DWI for the evaluation of osteoporotic, malignant, and infectious collapse. In an editorial, Finelli[44] believes it may be due to the inherently small studies and their patient selection, as well as the varied complex technical aspects of DWI.

Various other MR techniques have also been studied. Chemical-shift imaging does not aid in the differentiation between these different types of vertebral collapse. Baker and colleagues[6] tried chemical-shift imaging in the evaluation of benign versus pathologic vertebral collapse. Although the chemical-shift fat sequences provided greater definition, there was no difference in detection of marrow abnormality. In addition, the water chemical-shift images did not fair as well when compared with short tau inversion recovery (STIR) sequences for the evaluation of fluid. Other MR techniques such as out-of-phase gradient echo sequences and single-voxel proton spectroscopy may be helpful.[49]

## Clinical Implications

If findings favor a benign fracture, a follow-up study may be obtained in 2 to 3 months.[16,50] This should show some restoration in normal fatty marrow and less contrast enhancement.[5,50] If there is strong suspicion of malignancy, then the patient should be evaluated for sources of primary tumor.[50] If no primary tumor is found or known, a bone scan to search for additional metastatic foci is reasonable, as well as chest/abdomen/pelvis CT for possible primary tumors. Even with a known primary tumor, the vertebral collapse may still need biopsy for definitive diagnosis.

## Conclusions

Using conventional MR imaging, a diagnostic accuracy of up to 94% can be achieved even without clinical information. With the help of clinical information this accuracy level can achieve more than 90%.[44] Tuberculous spondylitis and multiple myeloma continue to be elusive in their appearance on both conventional and diffusion-weighted MR imaging. Therefore, the impetus of this article was to evaluate the techniques described in the literature to better diagnose this remaining ~5% of lesions. With the help of the rapidly evolving science of qualitative and quantitative diffusion-weighted imaging there is hope that this group of lesions can be reduced to a minimum.

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